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SILENCING THE DIESEL ENGINE

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Abstract

This article describes one answer, acoustic cladding, to the problem of reducing the noise radiated from the surfaces of diesel engines and other machinery. The authors believe that this method, which was initiated and developed by A.E.L., is an effective practical solution. It occupies little extra space, does not obstruct normal maintenance, and can be cost-effective when manufactured in quantity.

Other methods of noise reduction were investigated by A.E.L. before acoustic cladding was devised. For this reason, short accounts of these methods are included. It should be mentioned that air intake noise and exhaust noise are assumed to be dealt with by conventional silencers.

Introduction

The high speed, high efficiency diesel engine is probably the noisiest machine to be found in H.M. Ships. Sound pressure levels of 110dB and 120dB are not uncommon. The silencing of such a machine involves so many physical problems that a successful solution could almost certainly be applied to many other types of noisy machinery. In H.M. Ships, the emphasis on noise reduction is not so much for the benefit of the engine room staff, who can with some inconvenience wear ear defenders, but rather in respect of operational necessity. Underwater noise levels radiated from classes of vessel, for example minesweepers which have to deal with acoustic mines, must be kept to progressively decreasing maxima. It has been shown by trials that once a diesel propulsion engine has been mounted flexibly so as to minimise structure-borne vibration, then, in some frequency bands the airborne noise becomes the dominant source of underwater noise attributable to the engine. It was with the object of reducing airborne noise for this reason, rather than from the improvement in habitability, that acoustic cladding was developed. In many other possible applications, habitability is of course the paramount issue.

The handling of acoustic cladding is illustrated in Fig. 1 on a set as fitted in H.M.S. *Highburton* to the Deltic propulsion engines.

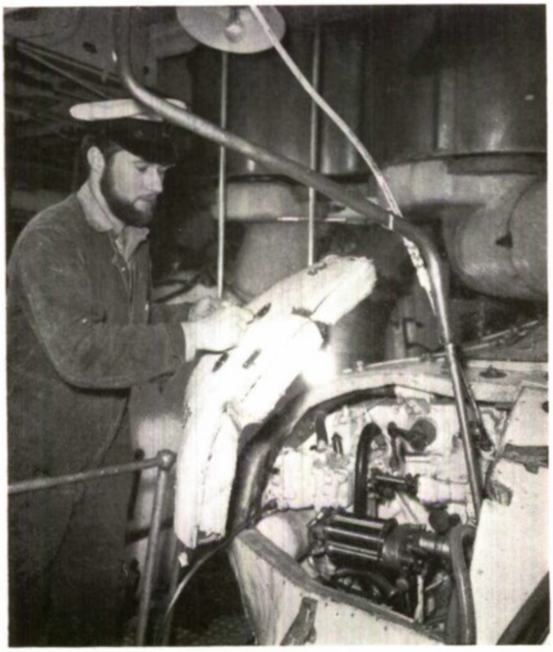


FIG. 1. In H.M.S. *Highburton,* C.P.O. N. Carter removing a panel of acoustic cladding preparatory to starting the starboard engine

Principle and Practice of Acoustic Cladding

The essence of the idea is the application of the mass-spring principle of attenuating vibration, by enclosing the whole of the engine with a massy covering which is flexibly isolated from the vibrating engine surface. By a suitable choice of materials and their properties, the vibration levels on this covering can be made much less over the greater part of the audio frequency spectrum than those which exist on the engine; the radiated sound-pressure levels will be correspondingly reduced, though modified by the modes of vibration on the cladding compared with those on the engine.

The relationship of the vibration levels on the surface of the cladding to the levels on the engine surface may be considered to approximate to that given by the single-degree-of-freedom formula commonly quoted for engine mountings, *i.e.*:—

$$T = 10 \log_{10} \frac{1+\delta^2}{\left(1-\frac{\omega^2}{\omega_N{}^2}\right)^2+\delta^2}$$

where T is the transmissibility,

ω is the frequency under consideration,

ω_N is the natural frequency of the system,

δ represents the damping of the system.

There will thus be vibration attenuation at all frequencies above $\omega_N\sqrt{2}$, increasing with frequency. But for frequencies below this, vibration levels on the cladding will be equal to or greater than those on the engine, hence the necessity to obtain as low a natural frequency as is practicable. In this manner the range of enhanced levels at low frequency is restricted. At certain higher frequencies, some reduction in attenuation may be caused by wave effects.

It should be noted that if the foam is sealed at the edges, thus containing the air in the foam, the air stiffness would give an undesirably high mass-spring natural frequency of 60Hz, with the mass and spacing used in practice. For various reasons, however, this effect is not thought to occur in the actual panels of cladding.

In practice the massy covering consists of lead sheet sandwiched between two layers of glass-reinforced plastic, to provide a superficial weight of about 24kg/sq. metre (5lb/sq. ft.). The flexibility is provided by a predominantly open celled polyurethane foam some 5 cm thick, of the softest grade which is commercially available. This combination provides a mass-spring system of which a small-size sample exhibits a natural frequency of the order of 30Hz, and which behaves as would be expected according to the transmissibility formula.

The massy covering is bonded to the foam, and in addition the inner surface of the foam is bonded to an inner skin of GRP to protect the foam from the ingress of fuel or lubricating oil.

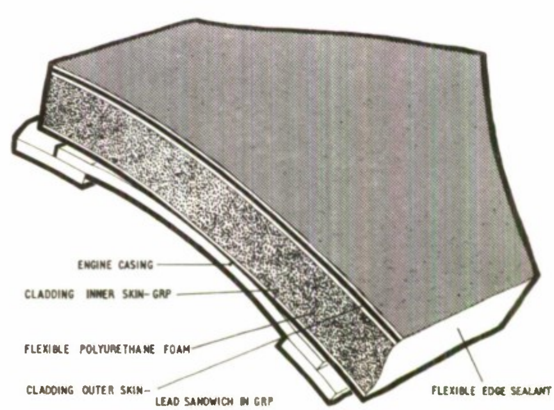


FIG. 2. Diagrammatic section of acoustic cladding.

This inner skin is shaped during production to follow the general contour of the engine. Finally the cladding is cut into suitably sized panels, and the foam edges sealed, also to protect the foam. The arrangement is shown in Fig. 2.

The engine is completely enclosed by such panels, which are clipped together in such a manner that each individual panel can be removed. In later designs, the principle has been adopted of having large panels which are bolted to brackets on the engine. Smaller easily removed panels are carefully located in the larger panels to facilitate engine maintenance. As the cladding is supported by the engine, the extra weight will of course have to be borne by the engine mountings.

Design of the first set of acoustic cladding for a large diesel engine was entrusted to Messrs. D. Napier & Son Ltd., where it was progressed under the direction of Mr. R. H. Taylor. This firm is now incorporated in Messrs. Ruston-Paxman Diesels Ltd. The cladding was actually constructed by Messrs. Goliath Ltd., of Sunbury-on-Thames, who contributed numerous practical ideas.

When an engine noise spectrum contains a fair amount of high audio frequencies, and there are no other major noise sources in a test cell or engine room, the subjective effect of the cladding can be impressive. Because of the high noise levels, it is dangerous to hearing to stay in the vicinity of an unclad high-performance engine, unless ear defenders are worn; and it may be impossible to communicate. When the same engine is clad, then, subject to the noise from other machines, it is quite feasible to inspect the cladded engine without wearing defenders, and to carry out a conversation in the immediate vicinity of the engine. It is important that the whole of the engine should be covered, and that treatment should be applied to any surfaces being driven by the engine. In H.M.S. *Highburton,* for example, the engines are bolted to a large metal raft, the noise from which limits the benefit due to the engine cladding. (There are of course vibration isolators between raft and hull). This is a separate type of problem which is now being dealt with. Much naval machinery is however directly mounted on flexible mountings.

It may be mentioned that the actual air-borne noise energy radiated by a diesel-generator unit capable of producing half a megawatt of power, may be no more than 50 watts.

The Nature of the Problem

When the requirement was first shown to exist, with special reference to minesweeper engines, a careful examination was made of possible methods of lowering the noise levels. Four approaches were considered:

- Fundamental reduction of noise at source, *e.g.* combustion noise, piston slap, gear tooth impact, etc.
- Covering the engine with commercial sound barrier material.
- Limiting the engine surface vibration by applying vibration-damping composition.
- Enclosing the engine in an acoustic hood.

The fundamental approach was considered to be an extremely expensive long-term project and would almost certainly involve extensive re-design of each type of engine. It was therefore decided to enclose the engines in a hood, but in the meantime to investigate the possibilities of covering or damping. The hood was needed for the Deltic 18-cylinder minesweeper propulsion engine developing 1100 BHP and the magnitude of the task necessitated entrusting the design and construction of such a hood to an outside contractor. It will be noted that an acoustic hood still allows any engine improvements to be incorporated, for example the oil-cushioned piston devised at A.R.L. for minimising the noise and shock due to piston slap.

Acoustic Hood

The most essential design features of an acoustic hood, whether intended for shore or ship use, are:

(a) that the hood and the noisy machine shall be completely isolated mechanically from one another.

(b) that the hood shall totally enclose the noisy machine and any rigidly connected supports,

(c) that the panels and framework shall be acoustically effective.

Thus in a ship with a noise-reduction requirement, in which the hull must support both the machine and the hood, it is desirable that both the machine and hood should be flexibly supported using separate sets of mountings.

Complete enclosure of the machine is absolutely essential if worthwhile noise reductions are to be obtained. Furthermore, the noise radiated from the walls of the air intake and exhaust ducts and silencers of a diesei engine will also be at a high level, and these will require attention if the benefit of the hood is not to be vitiated.

A non-magnetic hood was designed and built by Messrs. AEI Ltd., constructed mainly of aluminium. Very good noise attenuations, of the order of 30dB with very useful reductions at low frequencies were obtained at A.E.L. Acoustical efficiency was secured by:

(a) the use of a stiff and massive framework to allow the panels to achieve good low and medium frequency sound attenuations,
(b) the use of sufficient sound absorbent material inside the hood to limit the build-up of sound due to reverberation,
(c) the use of a complex panel design with selected materials to provide mass, stiffness and vibrational damping so as to secure optimum attenuation for a given weight,
(d) enclosing the support raft in the hood.

This type of acoustic hood, effective as it was, proved to have a number of practical disadvantages when fitted in H.M.S. *Highburton*,

(a) it occupied a great deal of space,
(b) once the panels had been removed engine maintenance was then impeded by the presence of the framework,
(c) removal of an engine for overhaul or replacement involved dismantling the hood framework sufficiently, and later re-assembling it, this procedure taking some weeks of re-fit time.

Sound Barrier Material

The first approach, other than using a hood, was to consider covering the whole surface of a Deltic engine at A.E.L. with a commercial sound barrier material. Again, to achieve any worthwhile effect with this technique, almost complete coverage is essential. Fig. 3 shows in principle the basic requirement, in which an imaginary noise source in which sound energy is radiated equally from all portions of the surface is covered by a sound-stopping material. It will be seen, for example, that covering half the surface with a perfect material will only reduce the noise level to 3dB, *i.e.* a change almost imperceptible to the ear, and that unless more than 99% is covered, the full effect of a material giving more than 20dB attenuation may not be realised.

In fact, it was found possible to cover about 90% of the area with a commercial sandwich type sound barrier material consisting of a

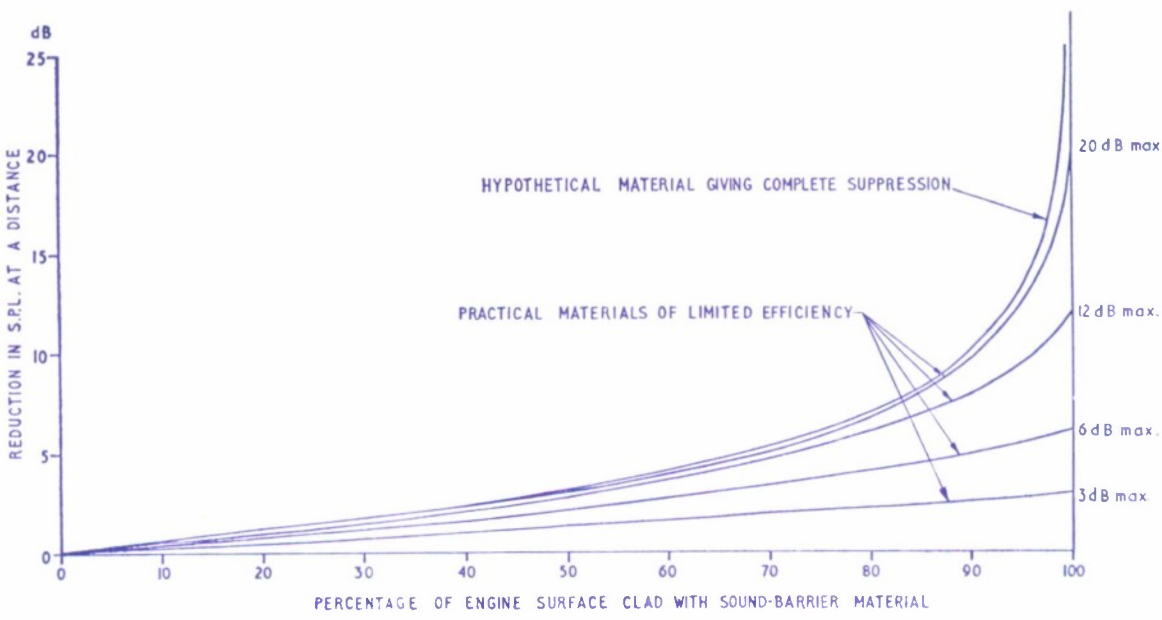


FIG. 3. Theoretical effect of cladding an engine assumed to be radiating sound energy equally from all portions of its surface.

layer of aquaplas damping compound between two $\frac{1}{4}$ in. layers of polyurethane foam, and coated on the outside with a material intended to be oil-resisting. The weight of material was about 1lb. $2\frac{1}{2}$ozs. per sq. ft. The material was secured to the engine surface with adhesive.

Measurements in one-third-octave levels of sound pressure showed that at about 1 kHz, reductions in levels for four representative positions in the engine test cell were of the order of 10 - 18 dB. (The engine surface, of course, does not radiate to the same extent from all areas). Below 1 kHz reductions fell away to negligible amounts at 250 - 300 Hz. These improvements were thus useful, but inadequate at medium frequencies.

Damping Composition

The second approach was the application to the surface of the engine of a panel damping composition, Type EP27A50, supplied by Admiralty Materials Laboratory. This composition, of which the mix is regulated according to the expected working temperature, produces an extremely high rate of decay of vibration when applied to a metallic structure. Demonstrations in which similar structures, bare and coated with composition, are struck with a single blow of a hammer show spectacular differences in the level and persistence of the emitted noise.

The aquaplas-clad engine was again used, but with A.M.L. damping composition applied to the gear box end of the engine. In this area, the phasing gears, which transmit power to the crankshaft from the three banks of cylinders, set up considerable levels of vibration in the phasing gear covers. Airborne noise reductions of the order of 10 - 15 dB above 1000 Hz were obtained, but of less than 5 dB at 500 Hz. The general conclusion was that the use of damping composition applied directly to the engine surface gave a useful, but insufficient, reduction in noise levels.

Acoustic Cladding

It was apparent that the commercial-type sound barrier material was inadequate for all but the higher audio frequencies. It was therefore decided to try the effect of much massier material. A brief experiment was conducted with a $\frac{1}{2}$ in. layer of A.M.L. damping compound on top of the sound-barrier material (in effect deliberately using a massy layer instead of a thin oil-resistant covering). This combination was applied to the rocker box cover of a Foden FD6 Generator engine, and vibration levels on the cover and on the damping compound were measured using an accelerometer and compared.

Results were sufficiently promising for a further experiment, and one of the three crankcase covers of a Deltic 18-cylinder engine, an area of about 5 sq. ft., was covered with a 2 in. thickness of very soft flexible foam and a $\frac{1}{2}$ in. layer of damping compound. Local airborne noise levels were of course governed by the noise emanating from the remainder of the engine; however, measured levels of vibration confirmed that considerable noise reductions might be expected on a completely cladded engine. Vibration levels were in fact reduced by 40 dB at 500 Hz.

Following this, a 6-cylinder 2-stroke 60Kw Foden Diesel Generator unit in an A.E.L. test cell was fitted with an experimental version of acoustic cladding. At the generator end, polyurethane foam was secured directly to the metalwork and then sprayed with lead oxide in resin. At the engine end, a supporting framework was bolted to the engine and covered with perforated metal to which foam was secured. The massy outer surface was made of modified damping composition. Care was taken to limit any noise leakages at penetrations of the cladding required for services such as fuel and water. Measured noise levels of the cladded engine were considered to be satisfactory. At 500 Hz, the unclad engine

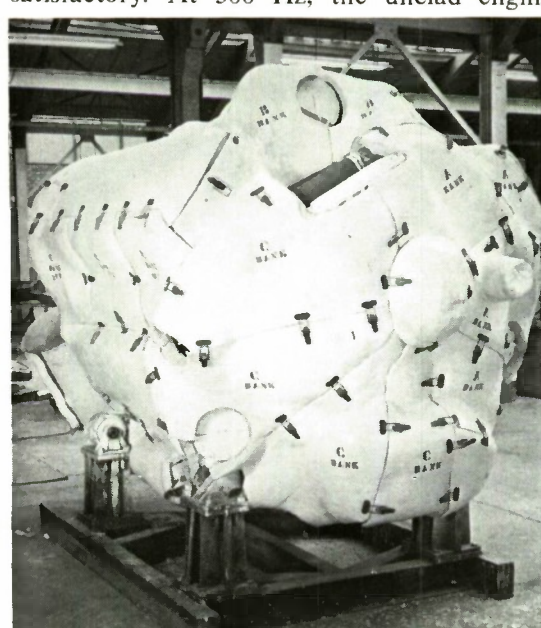
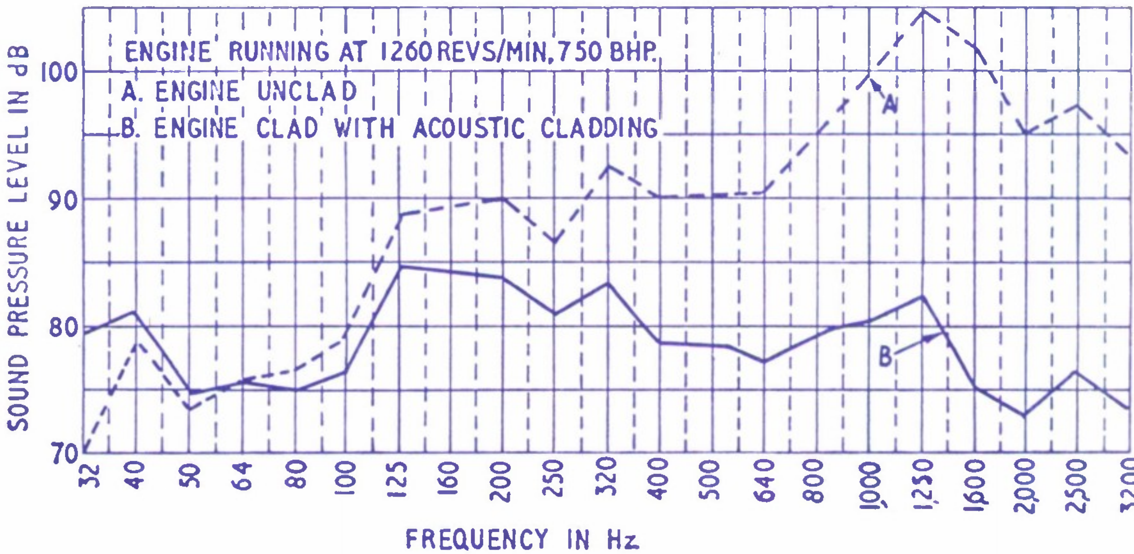


FIG. 4. Original design of Deltic Engine Cladding.

produced a level of 98·5 dB at one test position; with the cladding, the level was reduced to 74·5 dB.

Complete sets of acoustic cladding have now been built for Deltic 18-cylinder engines, Foden diesel-generators, and a Paxman Ventura Mk. II 8YJC 8-cylinder diesel-generator set. The performances of these cladding sets have been evaluated at A.E.L., and that of the original cladding fitted to the Deltic engine, Fig. 4, is illustrated in Figs. 5a and 5b. It will be seen that if performance is



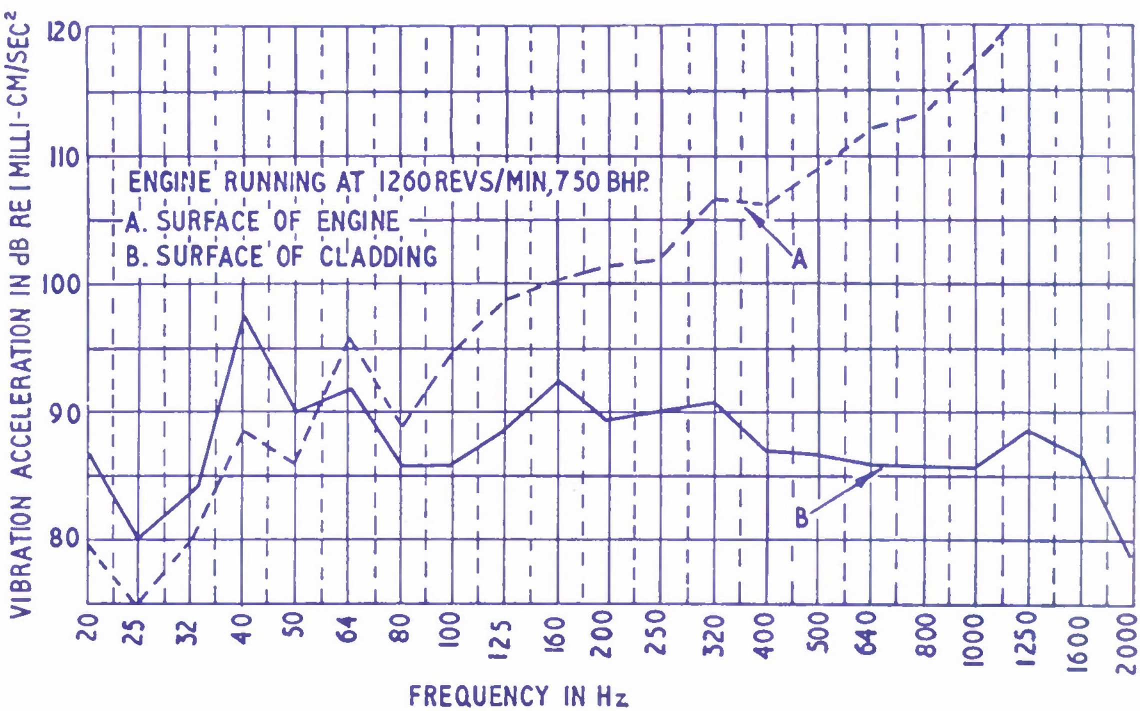


FIG. 5a. Measured acoustic performance of Deltic Engine Cladding.

FIG. 5b. Measured effect on vibration levels of Deltic Engine Cladding.

measured in terms of vibration reduction, this is much better than was observed for air-borne noise, *e.g.* at 500 Hz, 22 dB for vibration, but only 11·5 dB for noise. It is believed that this was due to the lower limit set by ambient noise in the test cell from noise sources external to the cladding, *e.g.* the engine air intake and exhaust ducts. A cladded Foden Generator Set was demonstrated at the A.E.L. Open Days Exhibition in 1970. The cladding for this was manufactured by Messrs. B.T.R. Ltd.

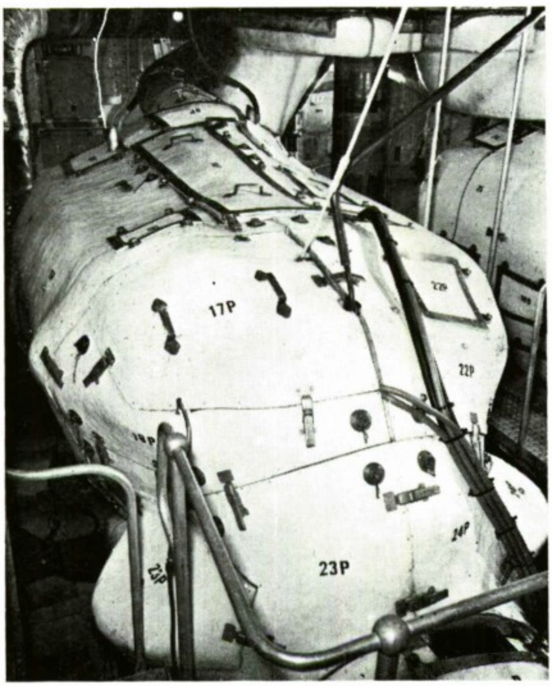


FIG. 6. Acoustically clad Deltic propulsion engines in H.M.S. *Highburton.*

Acoustic Cladding in Ships

Deltic 18-cylinder propulsion engines and Foden diesel generator sets in minesweepers have been experimentally fitted with cladding. The latest type of cladding, fitted in 1970, is shown in H.M.S. *Highburton* (Fig. 6). The relatively compact nature of the cladding is clearly shown. Results from this, though good, are as previously mentioned affected by radiation of noise from the metal support raft on which the engine is mounted.

Materials and Manufacture

Foam

The foam, which acts as a spring in acoustic cladding, must allow the system to have a low natural frequency with preferably a low gain at resonance, *i.e.* a low Q. In a batch test, the foam sample with a known super-imposed mass rests on a base plate driven by a vibration generator. Vibration levels on this base plate and on the mass are measured with accelerometers, and the natural frequency determined directly.

Open cell flexible foams in which the cells are intercommunicating are found to be better than closed cell foams. This is probably due to the more vigorous rebound of the latter type, in each cell of which a gas is sealed. Aeropreen polyether polyurethane AOP35 foam (now Dunlop D4) has so far been considered to be the most suitable and is stated to have the following physical properties:—

Density	20 - 22 Kg/m^3
Tensile Strength	0·6 - 0·9 Kg/cm^2
Elongation at Break	225 - 250%
Compression Set	8% max.
Hardness Index	7 - 10 Kg

It possesses acceptable resistance to oil, fuel and water, but like most open cell foams burns readily, aided by the ample supply of air in the pores to support combustion. A fire retardant version of this grade of foam is therefore always used to reduce the fire hazard. Very recently, a new and greatly improved fire retardant foam has been introduced by Messrs. Dunlop; this shows much promise for the acoustic cladding application.

Outer Surface Mass

The mass of approximately 24 Kg/sq.m., which is supported by the foam, needs to be evenly distributed over the outer surface however complex its shape may be. Cost, availability and ease of working considered, lead sheet 1·7 mm thick is the best material for this purpose. However, it generally needs protection from physical damage, this being provided by an outer skin of resin bonded fibre glass.

An alternative approach is to build up sufficient mass by several spray coatings of heavily loaded formulations. Contraction on curing, flammability, uneven mass distribution, toxic hazards and poor adhesion were among the problems encountered that eliminated known sprayable materials from further consideration.

Edge Sealants

Unfortunately the open cell foam required can act as a highly efficient sponge for fuel or oil from an incontinent engine. To prevent the build up of such a fire hazard it is essential to prevent ingress of these flammable liquids. Most of the foam is suitably protected by the mass layer and the inner skin, but on all panels there is at least a 5 cm width of foam exposed at the edge.

This edge must therefore be coated with a sealant that is flexible, impervious and resistant to fuel and oil, and that adheres well to the foam.

Most development effort on sealants is directed at evaluating spray or brush applied materials. A brush applied water-based PVC formulation is used at present for prototype cladding sets, but sprayable compositions are being assessed for production purposes.

Cladding Manufacture

The method of manufacture has varied somewhat according to experience gained and facilities available, so a typical construction is described.

The first operation is to envelop the engine in a close fitting sheet of polythene, held in position by $\frac{1}{2}$ in wire mesh and then sprayed with a rubber base solution. Alternatively the contours can be simplified by forming a framework that has been off-set from the engine in some places. A resin bonded fibre glass diaphragm is layed up on this envelope to give a firm support on which to form the inner skin proper from 2 layers of 2 oz/sq.ft., chopped strand fibre mat in polyester resin. This skin is then cut according to plan to give panels, the size and shape of which are determined by location points, ease of fitting and engine access requirements. They are then stripped of their wire and diaphragms, and major cavities in their outer surface are filled with foam off-cuts to give a relatively simple surface on which to adhere the 5 cm thick foam sheet.

A glass reinforced skin is then layed up on the outer foam surface to give a base on which to form the lead sheet in 10 cm wide carefully butted strips. Each strip has a few holes in it to allow excess adhesive and entrapped air to escape. Fig. 7 shows cladding at this stage prior to a final reinforced top coat of resin that incorporates a close woven plain weave glass cloth to give a pleasing finish. The exposed foam edges of the panels are then coated with a sealant; clips and handles are attached to the outer skin where required, and panels are marked with an identification number to assist in subsequent assembly on an engine.

FIG. 7. Laying lead sheet to form the outer skin of acoustic cladding.

During manufacture frequent partial assembly of panels on an engine is necessary to help in obtaining satisfactory butting of adjacent panel edges. Carefully located holes must be cut to allow passage of service pipes and cables through the cladding. This exposes more foam to be sealed, and when cladding is fitted for use every effort must be made to reduce the possibility of noise emanating from these points.

It can be seen that the construction of a prototype cladding set requires a high labour cost compared with that for materials. The manufacture of prototype cladding to fit a 1000 h.p. engine might take nearly a ton of materials and cost perhaps £10,000; but it is considered that on a production basis, using moulds for the inner skin, the cost could be very substantially reduced.

Ship Fitting

Preliminary Preparations

Although one of the undoubted advantages of acoustic cladding is that it occupies very little extra space it is surprising how many difficulties have to be overcome to enable an installed engine to be adequately clad. Due to the lack of standardised engine room lay-outs, it is essential to make an early inspection of this area to see what modifications are needed to decks, pipe runs or the cladding itself to ease the task of fitting.

This problem is highlighted by a report from the Planning Manager of H.M. Dockyard, Rosyth. The report comments on the installation of Deltic cladding sets in H.M.S. *Bronington* based on the prototype installation of similar sets in H.M.S. *Highburton* in Portsmouth Dockyard. On one vessel the engines are mounted on a raft which is supported on PD-type shock and vibration mountings; on the other the raft is on experimental constant position mountings. Only one of these vessels had exhaust scrubbers fitted; and the alignment of engines with the additional weight of the cladding was made more difficult in both cases because the engine feet were not accessible to enable shims to be fitted in the normal manner. Admittedly, however, H.M.S. *Highburton* was exceptional in that she was used as a trials ship.

Other comments in this report on ship fitting include criticisms of the use of stub-pipes instead of moulded flexible connections for fluid systems. It also itemises modifications found to be necessary for salt and fresh water suction and discharge pipework layout, lub. oil systems, air induction and exhaust systems. Difficulties in manhandling the larger panels through the engine room hatch are also mentioned. Normally however cladding would be fitted when an engine is first fitted or at the time of an engine change.

Fitting and Maintenance

The most important aspect of fitting is to bear in mind that the maximum prolonged temperature that the cladding can tolerate, without affecting the foam excessively, is 120°C. Therefore great care must be taken to thermally insulate exhaust stubs beneath the cladding and any other hot surfaces in close proximity. Charring of the outer skin has been known, caused by radiated heat from unlagged exhaust piping just outside the cladding. Triton Kaowool is recommended for any thermal insulation required.

All H.M. Ships with acoustic cladding fitted to their diesel engines, or generator units, are issued with a set of instructions on the care and maintenance of the cladding. These emphasise the need to eliminate liquid or gas leaks and advise that cocks and valves should be wired to prevent them being knocked open when fitting or replacing panels.

Experience has shown that maintenance of the cladding in a safe and efficient condition is best achieved by following this routine:—

(a) Inspect panels near hot piping and improve thermal insulation if charring is observed.
(b) Maintain good insulation of electric wiring where it passes through the cladding.
(c) Locate and eliminate any exhaust leaks.
(d) Locate and eliminate any fuel or oil leaks, and clean badly-splashed panels with detergent solution.
(e) Inspect for breaks in the panel edge seal and repair with material provided.
(f) Remove for repair or replacement any defective joining clips and replace according to instructions.

Precautions

Concern has been expressed at the possible undesirable thermal insulating effect of the cladding; but all operating experience with water-cooled engines, even under simulated tropical conditions, has shown negligible rises in engine surface temperatures of cladded engines when compared with unclad engines. Nevertheless it is still recommended that clad engines should be off-loaded for a period before shutting down, and coolant water temperature observed for a time after shut-down.

In some cladding applications, *e.g.* the Paxman Ventura Mk. II 8YJC generator sets, an air supply is provided for cooling the space between engine surface and cladding. This should be used whenever the engine is running and for a short time afterwards. When the engine is running cladding panels should only be removed for essential engine maintenance and should be replaced as rapidly as possible. This is because air will escape from where they are removed, thus possibly reducing the flow through spaces which need to be cooled. Originally it was arranged to maintain a small flow of air between engine and cladding to prevent entrapped oil and fuel vapours from concentrating sufficiently to form a potentially explosive mixture with air. However, chromatographic analysis of atmosphere samples taken from selected air pockets indicated that this was an unnecessary precaution. The use of forced cooling air must be made with great caution, as draughts are renowned for accelerating the rate of spread of fire.

The Future

Laboratory tests and evaluation of prototype cladding sets both demonstrate the effectiveness of the mass-spring system. It is also established that good attenuation of air-borne noise depends upon the completeness of the cladding around the noise source. Cladding could be made more efficient in the future by planning ship installations and modifying the engine's external outline and fitting so as to simplify the cladding design. One obvious requirement is to reduce to a minimum the number of penetrations through the cladding of service pipes, engine feet and instrument cables etc.

The wide range of enquiries received, as a result of technical press comment, show that an amazing variety of noise problems exists. Industrial application is however unlikely to be very great until either the cost of cladding is reduced or legislation enforces expenditure on non-profit making noise reduction. Commercial application enquiries are handled by G.E.C. Diesels Ltd. (Ruston Paxman Diesels Ltd.) who hold the manufacturing rights:- British Patent Application No. 51313/67. It has been agreed that A.E.L. will advise on any potential M.O.D. applications.

Manufacturing labour costs are high compared with material costs, so that acoustic cladding will best be made more economically attractive by simplifying panel shapes and methods of preparation. It is also considered that there is still need for improvement in edge sealing.

If cladding can be tried out on a noisy machine where there are no fears of it being contaminated by a liquid, this will eliminate the need for edge sealing and allow for the effects of perforating the inner skin to be determined. It is possible that in this way improvement will be obtained due to the sound absorption properties of the polyurethane foam.

A close watch is being kept on the flexible foam manufacturers, as it is known that they are making an intense R & D effort to reduce fire hazards associated with their products. Any improvements will be incorporated, though all sensible precautions have been taken and materials are tested at A.M.E.E. and C.D.L. Portsmouth for fire spread and smoke evolution characteristics. Development will no doubt progress according to the demand as knowledge can be gained from solving problems presented by any new application. It is believed that the method could well be used for reducing the noise radiated by pipes and ducts, electrical machinery generators, compressors, gearboxes and other machinery where temperatures are at a reasonable level.

Acknowledgements

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OBJECTIVE COURSE DESIGN IN THE R.A.N.

Lt. Cdr. C. W. Dunnett, B.Sc., Dip.Ed., F.I.T.O., M.A.C.E., R.A.N.
H.M.A.S. *Watson*

One of the wonders of the ancient world which remain today are those immense structures built by the Egyptians. The planning and building was so successful that the pyramids remain as one of the greatest epitomes of an objective system in the history of the world. The objective was clearly 'to build a pyramid". The components of this structure were clearly defined level by level, and until a level had been constructed the next level could not begin. The end product was to serve as a monument, and a burial place to last for all time. This remains to be seen, but on present form the architecture seems to be a stayer!

When selecting the form of his monument, the Pharaoh in question must have had many designs submitted, but once the particular one was selected, the method of construction was implicit. Although, as long as the end product was achieved, as defined, the method of construction itself was unimportant, unless external parameters came into being. Items of material, availability, cost and time may have affected the decision of method, but only in as far as they affected the environment of the task and not the task itself, for the task itself had a clear, precise, end product. These analogies and comparisons still apply in our daily lives, having selected an objective, the development of its achievement is an independent exercise. Training and education remain surprisingly on the touchline of the field of objectivity and the means of achieving this objective quite unimportant.

It has been the impetus and control of the environmental parameters that has forced us to be cost conscious which, in turn, has led us to apply the ultimate methodology into our training methods and educational processes to achieve carefully stated aims in the best, and usually cheapest, possible way. This Training Technology has become the prime science in the planning and approach to activities which have otherwise been conducted in many different ways. One particular forté of many course planners has been the end product that was tested, and which has always been assessed in some way or other. Unfortunately, this end product has never been related to the job in the actual assessment and testing methods which were applied to it. The testing which has taken place has always been on the success, or otherwise, of the student to repeat or apply the facts taught him during the course! Since the course itself often had no defined objective we have had rather an "etheral" training situation which may well have produced what was required, but it certainly produced other skills or knowledge as well, whether or not they were relevant.

To revert to my introduction in the realm of Egyptology, perhaps the Egyptian construction company that had been told to "build a tomb" might have produced something rather different from a pyramid had they been left to their own ideas. The prime difference is one of relationships. As long as the training relates to the objective and the objective relates to the job, then the whole process is continuous and definite: Equally the testing methods will be applied as easily and equally to "on the job" performance as to "end of course" performance and although great play is made of defining objectives, unless they relate to the job in question they are quite valueless. This method, process, suggestion or call it even a system, has always been acknowledged as necessary, but was intuitive. Only the objective system will ensure by design that the links and relationships are forged, their very forging will provide base metal for a much greater refinement of method and subject than ever was previously possible.

The function of the trainer in forging the links of the system is as complex as the function of the employer in the end product. He must not only analyse the requirement but he must also choose the method of learning and, by virtue of his responsibility to "he who calls the tune", this method must be cost effective in whatever terms 'cost' is evaluated. I would hasten to emphasise the importance of the word "effective". In that much hackneyed term, the word "cost" has tended to influence the choice of a solution, resulting in an imperfect answer to a problem. If the problem exists, it must be solved, or the problem remains, regardless of how much money has been saved on an incomplete solution or how low the 'cost' in whatsoever terms it is measured. In choosing methods of training, a technologist must rely on his own training and experience, but by conforming to the disciplines of the new "Programme Learning", which is the "father of this technology", his choice will be 'controlled', rather than, 'influenced', by habit, or other such factors of the establishment.

This programming process supports the logical development of an 'instructional design' or a 'training system'. Such a system must effectively achieve its intent (regardless of the mode of implementation) and must embrace at least the following facets:

(a) A careful analysis of the operational environment into which the trainee is to graduate, in order to determine the requirements.

(b) The development of instructional and behavioural objectives which if achieved, will prepare the trainee to embark on the translation of his newly learnt skills into the operational environment.

(c) A development of a training system and design based on the stated objectives (which must be validated).

(d) A means of validation or testing to link requirement and training method with trainee achievement.

When properly formulated within the above parameters, an objective system will have, as its very heart, clearly defined objectives.

Such objectives will always clearly state:

(a) What the trainee will be able to **DO**

(b) The conditions under which he will **DO** it

(c) The standard (or criteria) of acceptable performance.

Statement (b) above will be the "link" to tbe operational environment enabling the Training Officer to retreat from some impossible operational training aims attempted in the training school. (It would be difficult indeed to train a man to swim in the absence of water). There will be many training subsystems developed, but to be valid they must he objectively orientated.

It is a real temptation to reject the whole technology out of hand and settle back into the plush comfort of our accustomed practice. Deeper issues beneath the surface of systems training are raised. We should not question the concepts, for they are inviolate. We must consider instead the best way to approach the array of methods and substance available for our use and application in this new science.

The solution to a training problem must be found unless we assume that no problem exists. The choice of a particular system is itself relatively unimportant as every system will of necessity fall back to the same fundamentals. The stages of development themselves will not necessarily even be worded in the same way, but the underlying logic of progression by objectivity will remain. When a system has been completed and applied, feed-back in 'continuum', must exist; that is, the end product will be tested and validated against the same criteria as that decided upon in the first analysis of performance in the operational environment. Any direct feed back in the system will always include every stage prior to that form from which the feedback originated, that is, to leapfrog stages backwards is just as impossible as missing out a stage of development.

The particular total system in use will inevitably, vary, not only in its objectives, but in its own sub-systems of achieving them. One particular sub-system that is so often missed is that of the Course or Training Design itself. The " System " clearly designates particular objectives to be achieved by a particular course, but how often do we set about actually developing those objectives and only those objectives ? Too frequently the course design team spend many hours of discussion and testing only to step aside under a different ' hat ' to write a syllabus, and then to revert to their system to systematically test whether their syllabus will match, relate or produce the objectives that were so clearly defined. Unfortunately this ' gap ' of syllabus in course development is so easy to side step, particularly if the objectives happen to have been achieved, of course many other skills will exist but in retrospect everything appears to have been so very logical.

It was because of this rather accidental course training development that I devised the synthesis based upon a ' 7 levels ' approach more fully developed in ref (3) — in brief the levels are:

1. The jargon, definitions or implications of the " whole ". The language of the topic under discussion.
2. (a) The recognition of major components and their location.
   (b) The recognition of sub components and their location.
   (c) The recognition of knobs, switches or items of specific requirement in the skill, and their location.
3. The statement of the effect or action and recognition of the effect or action of the knob, switch control or item under consideration.
4. The carrying out of the operation on the particular knob switch control or item, isolated from the whole sequence within which it is normally carried out.
5. The statement of drill or sequence of operation with the aid of a check off list or other reference.
6. The carrying out of the drill sequence or operation or action when told to do so.
7. The recognition or selection of a situation when drill sequence operation or action is required.

The principle objective of this very mode of creation must be clearly stated at the outset, that is to synthesise the syllabus or course, to actually develop, along planned lines or sequence of enabling objectives, any given terminal objective. It is to these ends that the ' Trainee ' must strive. Perhaps one of the best ways to explain the whole process is by example, and a recent project serves very well.

The topic of investigation was the training of seamen in the RAN, for whom very precise, user requirements exists. Unfortunately, as in all training the wording of the ' user ' requirements was vague to say the least, but the areas of skill had been extracted even if the level or standards stated were intuitive in the mind of the user.

This problem of vague intentions may serve as an example to many in the field; as to apply a precise technology in one swoop would be professional suicide in any stable ' establishment ' and the RAN in their wisdom had applied a simplified system which served to bridge the gap from the old to the new. Such a simplified system invited the user in all areas to define the levels of requirements within one of the three areas:

1. *Expert* —
   Needs no supervision, has reached a high level of performance skill, could cope with difficult and unusual problems, that is, could apply knowledge or skill to new situations.
2. *Effective* —
   Needs occasional supervision, has reached an effective level of performance skill, could cope with common problems.
3. *Trained* —
   Has done the task in the training situation and needs careful supervision to do the task in the operational situation.

These levels were called *Course Training Standards.*

It is clearly evident the objective of the best of level 1, (and even the worst of level 3) is almost clearly defined, level 2 however has a continuum of interface between level 1 and level 3, which are always set when the term ' supervision ' appears (and words like occasional).

The task of the experienced technologist is to clearly establish exactly what was meant in all levels and particularly those skills assessed as level 2. Inevitably the grey areas become very grey and even cloudy when one tries to define how 'well' a man is able to do something. Is it under supervision? If so how much supervision? How often? and how much error is allowed? Specific terms must be produced and it was to try to make this problem capable of being discussed that I devised an Algorithm based on the 7 levels[5], such an approach at least allows, and presents, a basis for discussion, and even argument of the level intended. One of the objectives of the Algorithm is to decide on how much, or what 'supervision' means. To this end the Algorithm present the two distinct possibilities each of them quite distinct in doing something with help *i.e.*—

1. Doing a job or performing a skill or operation by reference to some printed manual, document or word.

or

2. Doing the job or performing the skill under the personal guidance of an expert.

It is assumed that the second way was much more easily performed than the first and by deciding which of these two methods were demanded by the job in question, a basis for further discussion can evolve. If it was method 1, then the accuracy of translation of each word or action can be precisely measured, and if method 2, then the frequency of guidance can be defined, or limited to be of sequence direction only. The evolution of a definitive meaning quickly enables an investigating technologist to establish the true intentions of the user or employer. In the Seamanship project the expansion of the three levels of Course Training Standards into one of seven precisely defined levels of objective training could now begin. Each Course Training Standard was discussed and transposed into a precise level by and with the user experts. No ambiguities were allowed and each and every skill was argued out to its fullest extent, at no time were the investigating consultants/technologists allowed any 'ideas' of their own, their sole task was to extract the true intentions of the original writers of the Course Training Standards by using and explaining the Algorithm already discussed. Having completed the initial investigation each objective was then documented on the 'objective statement' form illustrated in Fig. 1. The use of special forms encourages uniformity and invites precision which is the fundamental of the exercise at all stages.

DATE 24th January, 72
COURSE AB SEAMANSHIP

TRAINING OBJECTIVE
STATEMENT

TASK / SUBJECT No. BOATS LEAD AND LINE 5D

REFERENCES: SEAMANSHIP MANUAL B.R. 67(1) Page 416

1. PERFORMANCE:

To take a sounding from a power boat using a boats lead and line, and to call the depth of water.

2. CONDITIONS:

In a boat in water of unknown depth by the trainee.
The boat should be underway at 1 kt.

3. STANDARD:

As per test spec.

FIG. 1. Objective Statement.

TEST SPECIFICATION — AB SEAMANSHIP — COURSE

FOR TRAINING OBJECTIVE NO. 5D — 24th January, 72 — DATE

REQUIREMENTS	TIME
MANPOWER PO/LS - 1 as tester	10 minutes per trainee
MATERIAL (Software) Check list - 1 per trainee	N/A
EQUIPMENT (Hardware) Boats lead & line - 2 Boat - 1	N/A

METHOD

A boat will be provided in water of known depths, graduated by coded markers.
Each candidate will be tested using a check off marking sheet in (a) making up line, (b) taking a sounding (c) calling the correct depth.

CONDITION

Using correct procedure, not more than 3 soundings per man.

MARKING/STANDARD

Two out of three correct in all respects.

FIG. 2. Test Specification.

The lower section of the objective form itself encourages the technologist to expand the objective into precise 'standard'. However we decided that in these early stages it would be wiser to refer to a "Test Specification" on which would be the full details of the standard and more to the point, the manner in which it would be tested. Such a test specification to match the objective already quoted, is illustrated in Fig. 2. The

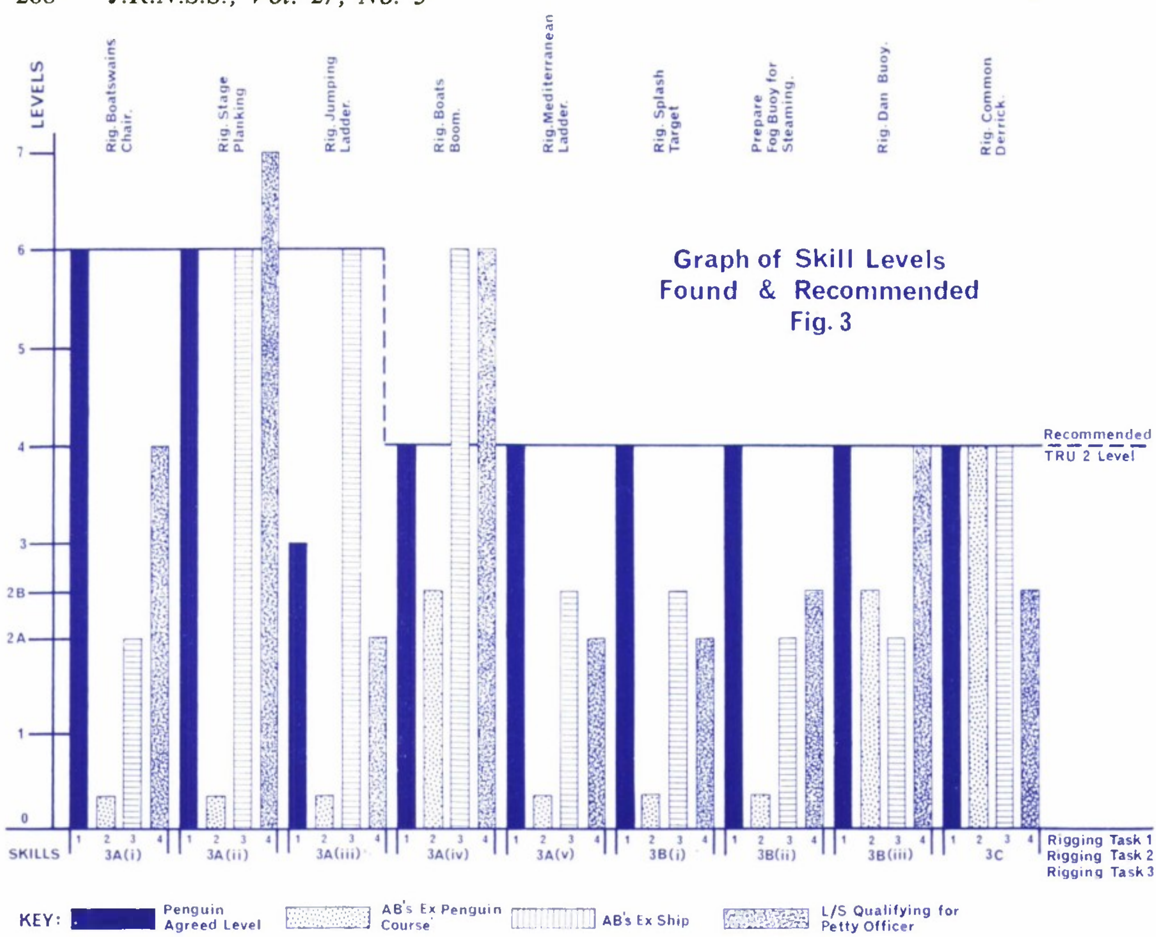


FIG. 3. Results of Seamanship — graph.

derivation of Test Specifications will often involve the construction of check off lists, and in turn 'weight' marks associated with each item. Even though the weights of a process are not perfectly quoted at the first try, the true weight will evolve with use and correction during the application of such a Test Specification. It is here that a form of feed back exists within the sub-system of the whole, allowing for correction at design stage before the whole system has even been established.

To continue with the Seamanship exercise, a procedure was then devised which may well be considered underhand. However, the desired result of establishing both the correctness *i.e.* possibility, as well as the validity of the quoted standards was to be achieved. Sets of sailors were tested to the newly written objectives by the Training Research Team. These sets came from three areas:

Set 1. Having completed a conventional course.

Set 2. Having completed a course, and done a year at sea 'on the job' for which they had been trained.

Set 3. Some more experienced men at two levels above the Able Seaman and who had all had at least two jobs at sea since their earlier course.

The results of one sequence of tests is illustrated in Fig. 3, their actual level (in 7 level system) found being tabulated against the decided level originally estimated by the training school. As a result of these tests the training school was then most eager to ammend their suggestions (sometimes up as well as down !) and complete agreement was very quickly established. It was to these finally agreed levels that the synthesis of a training situation could begin. The objective writing

OBJECTIVE ANALYSIS	REFERENCE
for BOATS LEAD & LINE	Trg. Objective No. ....5D....
	Total No. of E.O.s ....5.....
	Course ..AB SEAMANSHIP..........
(Course Training Objective in brief)	Date · ..24th January 1972...

REF.NO.	ENABLING OBJECTIVES	TRG. METHOD	TIME EST.	TYPE OF PERFORMANCE CHECK	% EST.
5D/1	Jargon, definitions	Class	10 mins	Oral	100
50/2	Recognise in use and parts of line with cue card	Real	30 mins	Real	100
5D/3	Recognise requirements and use	Real			
50/4	State method of sounding with aid of cue card	Class	2 hrs	Real with Check off List	
5D/5	Take sounding to standard no assistance	Boat Jetty			

FIG. 4. Enabling objectives for 1, 2 & 4.

and testing that had taken place had not been wasted because all of it would be incorporated as terminal objectives of the new course when it was completed and the very compilation of the entire picture enabled the technologist to obtain an impression of the whole situation. At this stage, relatively inexperienced assistance could begin to take part in the project and be extremely useful, (inexperienced, that is, in the technology of training) and they would become familiar with the methods being employed, and be able to assist at earlier stages of future investigations. The first major task was to extract all the jargon, new words and definitions which are involved with each and everyone of the objectives.

If a full task analysis (R. F. Mager[2]) had been completed then this extraction of detail is or would have been part of that analysis, but it is my contention that in the first instance of carrying out a project, it is quicker, and certainly easier, to let user experts, with no technological background, simply construct lists of material based on their own expertise and instructional backgrounds. Of course words will be missing, but we found that the 'expert' was far more likely to include more detail and words of jargon than was actually required than not enough. Confronted with all the word lists, a 'pattern' of treatment was then evolved by one of the more experienced team. This 'pattern' was simply to extract generalities to be dealt with altogether at the beginning of the course, and leave specific details for the particular objective in question. For instance the list of words dealing with wire rope and cordage, read as follows:

Cordage	*Types*	*Wire*
Manila Sisal Coir Terylene Nylon		F.S.W.R. E.S.F.S.W.R. S.W.R. F.M.S.W.R.
Fibres Yarn	*Parts* Core Heart Strands Lay	Gauge
Glaze Cheese Parbuckling Friction	*Working Terms Used* Surge Veer Turn Up Coil Fake	Standing Rigging

Bends & Hitches	*Splices*
Catspaw Hawser-bend Sheepshank Monkey's-fist Heaving-line knot Constrictor Rolling hitch Clove hitch Half hitch Timber hitch Reef knot Bowline Bowline-on-bight Figure-of-eight Double sheet bend Single sheet bend Thorough footing Flat & round seizing Racking seizing Carrick bend	cut long short chain eye *Whippings* Sailmakers Westcountry American

The difference between realising that a reef knot was a knot, which is dealt with under the initial 'overall' jargon of whole rope and cordage section and actually recognising a reef knot is quite clear and the list in fact provides a pattern for the objective development. Each of the 7 levels is applied absolutely to each defined objective, the levels are each precisely defined themselves, on separate documentation if necessary, and each pro-

A/B SEAMANSHIP NETWORK SCHEDULE

Timing has been omitted for sequence purposes only

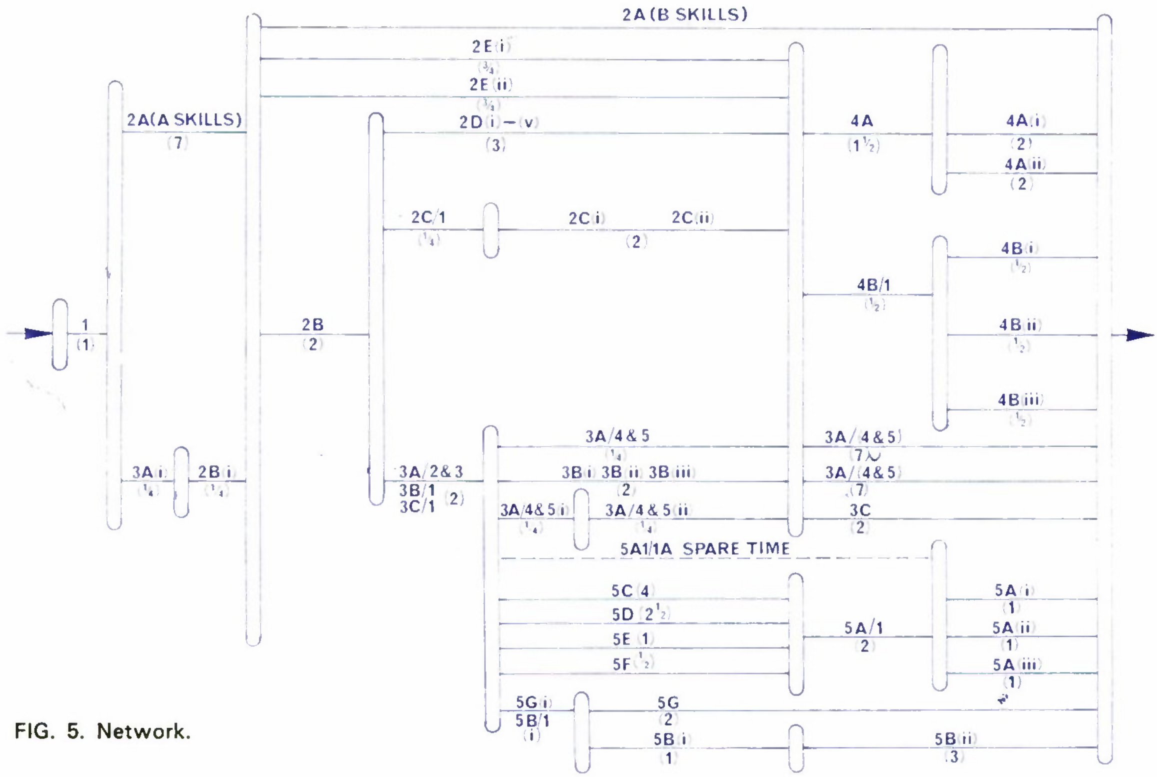
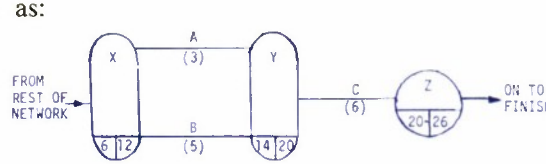


FIG. 5. Network.

vided with a test specification which must be met before proceeding to the next level. The particular set of levels, when documented were called the Enabling Objectives and the example in Fig. 4 expands into the levels required for the objective previously discussed in Fig. 1. Having completed all of the Enabling Objectives for each Terminal Objective then the whole content of the course of training has been achieved. This is really more 'aptly' described as the components of behavioural change necessary to achieve a stated terminal behaviour.

If there was only one terminal objective then a sequence of training would be quite straight forward but with many, as in the case of the Seamanship Project it is necessary to correlate each objective and Enabling Objective. For in many of the more specific skills required, such as operating a hoist or derrick it is very necessary to have completely mastered the more general rope and cordage skills as well as Blocks and Tackles. With all these interrelated topics a method of documentation was necessary which would present visually the whole relationship. This was achieved by Network Scheduling[1] and the completed Network for Seamanship is illustrated in Fig. 5.

Very briefly for those of my readers who have not met this method such a situation as:



could appear within a whole network 'sausages' x, y and z imply moments in time or stages of development. A, B and C are syllabus topics taking 3, 5 and 6 units of time respectively.

The two numbers in each sausage indicate on the left, the earliest time in the schedule, and on the right, the latest time in the schedule that each stage could be reached to 'solve' the schedule, everything into a 'sausage' has to be completed before proceeding outside. In this simple example A and B both must be completed before C is begun hence there are only two solutions of sequence, which will conform, these are A — B — C and B — A — C.

The whole network as illustrated in Fig. 5 therefore provides a method by which a regular timetable can be constructed, or planned around specific events, of both material and instructor availability.

Such a network is essential, both for course planning as a whole, and for any attempt at Free Running Training. Free Running Training involves the placing of individual trainees into specific learning situations but always according to a well defined sequence as presented by the network and letting them proceed at their own rate. The requirement to have alternative paths within the network is essential to the success of such a venture. The more 'packages' of training that are available to meet particular Enabling Objectives the more fluid and less 'Instructor bound' will the system become. Packages of training will relieve the Instructor from pure communicative roles for the more demanding (and cost effective) tasks of correcting, controlling and managing the training situations which are taking place around him.

These packages included in the 'course' can take many forms, all based on the principles and concepts of Programmed Learning. Booklets, sets of slides, slide/tape CCTV, AVIT[3] are but a few of them.

In the Seamanship project many packages were made by the team for the recognition and statement levels of the enabling objectives, Fig. 6, shows a trainee actually using such package which is an integrated written text with a simple objective of recognising the cordage in use in the Navy. This particular process only takes an average time of 8 mins. Other packages exist as sets of cards, professionally prepared, for learning both recognition of skills and simple sequence sets of 'how to do it'.

Such packages can be simple or complex such as the almost complete package deal as described in the use for Sonar Operator training[4].

With the whole sequence of training planned in this way, a free running situation is now possible. The only additional documen-

FIG. 6. A/B using 'cordage package'.

tation needed is a progress card for each trainee.

Ideally each enabling objective of the whole system will be undertaken by a programmed package, and an instructor allocated to oversee each section. However, until all the programmes are completed the instructor himself will have to conduct small conventional class groups within the whole course. The major control of the sequence of the course, will be the network schedule which, with its many routes will allow the trainees to be routed to available areas, just as fast as they complete each section.

Conventional examinations will disappear as each skill is defined and the ability of the trainee fully described. When a trainee is able to perform to the stated level, he has succeeded in his task as has the course in enabling him to do it. Competition within the course which is objectively laid down will rely entirely on time *i.e.* the only way left to compare identical performance will be the time taken to achieve it.

The accent has clearly changed from what A/B Bloggs knows, to what he does, and consequently a defined task within a job can either be performed satisfactorily or not, *i.e.* if 70% is the required standard then it is of really no great value to be up to 90% and the system will benefit only in the time it has taken to achieve the 70% — the time taken in improving to 90% was not required, either by the job, the system or the trainee. Training centred objectively on a job requirement must not be questioned, for by doing so we question the very job — this in itself may well prove necessary but it is not a training task. The trainer should ideally be in an environment which at least 'knows' what has to be done.

If we as training managers are to be sure of that, members of our trainee population will avoid the ' knowledge ' dilemma, I suggest we need to recognise the behavioural objective as one of the most powerful elements of Modern Training Technology.

In a recent paper, Mager provides a very suitable closing comment on our present state in this matter when he says:

> " . . . benefits to be derived from the application of these tools do not wait for more grant money, and they do not wait for the invention and development of more hardware. They wait only for all of us to stop talking about why it cannot be done, and go out and *do* it ".

References

(1) 'An introducton to critical Path Analysis ', K G. Lockyer—Pitman 1964.

(2) ' Developing Vocational Objectives '—Mager R. F. Fearon 1967.

(3) *J.R.N.S.S.*, **25**, No. 5. ' Development of a Training Module from an objective Task Analysis '—Dunnett.

(4) *J.R.N.S.S.*, **25**, No. 1. Audio Visual Training Methods, Development of Softwave.

(5) The Algorithm referred to is available on request to the Training Research Unit No. 2, at present based in H.M.A.S. *Watson*, Sydney, N.S.W.

Correspondence

To The Editor,
Journal of the Royal Naval Scientific Service

Dear Sir,

Many of your readers will have read elsewhere of the recent death of Professor F. V. Hunt of Harvard University. When I was working at HMUDE and TEE his was but a name, associated vaguely with the Harvard Underwater Sound Laboratory of which he had been Director, which had been dissolved at the end of World War II. After I moved to the USA Ted became a personal friend.

I was reminded of the HUSL (of which the Ordnance Research Laboratory is one of the principal offshoots) by Geoffrey Kirby's recent articles on the History of the Torpedo. It was largely as a result of Ted Hunt's foresight and guidance that the first American acoustic torpedo was developed from scratch and " fired in anger " within 17 months of conception with considerable success. Sponsorship of the project was obtained from the Mines Branch rather than the Torpedo Branch of the U.S. Navy Bureau of Ordnance, which is why it was known as the Mk 24 Mine. It was intended to be launched from an aircraft and had a 19 inch body. A modified version the Mk 27, had four 1 inch thick skids mounted on it to enable it to fit and swim out of a 21 inch torpedo tube. I must correct my friend and namesake on these points.

After the dissolution of HUSL unclassified work continued under Professor Hunt's direction in the Acoustics Research Laboratory of Harvard University under contract to the Office of Naval Research. Perhaps the best tribute to Ted's work in this period of his career is contained in his own valedictory Final Report: 1946 - 1970, NR - 384 - 903, under contract NOOO 14 - 67 - A - 0278 - 0007 (AD 708758).

Yours truly,

Geoffrey L. Wilson

IONIC SILVER AS A WATER STERILANT IN CONTAINMENT AREAS

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William Drake joined the R.N.S.S. in 1956 as a Senior Scientific Assistant at the Laboratories of the Institute of Naval Medicine, after obtaining a Fellowship of the Institute of Medical Laboratory Technology during a long service engagement in the Royal Navy. Was promoted to Senior Experimental Officer in 1970 and has been engaged on many aspects of environmental and occupational research.

Jack Elgie qualified as a Medical Laboratory Technologist during service in the Royal Navy. He also served in the Nuclear Submarine Programme and obtained M.I.Nuc.E. Joined the Institute of Naval Medicine in 1966 as a Senior Scientific Assistant to work on environmental problems and was promoted to Experimental Officer in 1971.

Duncan Walters graduated from University College Hospital, London, in 1951 and joined the Royal Navy in 1952. He obtained the Diploma in Industrial Hygiene in 1956 and the Diploma in Public Health in 1959. In addition to sea service in various parts of the world he has been attached to the Royal Marines, served in Her Majesty's Dockyard, Portsmouth, and has been Senior Medical Officer (Occupational Medicine) at the Institute of Naval Medicine since 1963.

For several years the co-authors have worked together on many projects including the production of pure sterile water from evaporators, problems involved in storage of water in G.R.P. tanks, and habitability and climatic trials.

Abstract

During routine bacteriological control of water systems in MOD(N) establishments, infection with the micro-organism Pseudomonas aeruginosa *was frequently demonstrated. Most natural waters are liable to contamination by this bacillus and in certain containment areas the use of chlorine as a sterilising agent is not considered advisable. Ionic silver is known to be an efficient water sterilant, and its effect upon this particular organism has been investigated.*

Introduction

Pseudomonas aeruginosa (a causative organism of the blue-green pus from ear infections) is present in sewage and is associated with numerous suppurative and generalised infections in man, and there is evidence of it being a cause of outbreaks of diarrhoea. It is much more resistant to the action of disinfectants and antibiotics than most other vegetative organisms and is replacing the *Staphylococcus* as the greatest concern in hospital-incurred infections. Water systems provide an excellent means for its dispersal. The strain used in this investigation was a particularly resistant form isolated from water in a containment area.

Recent work on sterilisation processes for distillates from evaporators, showed that ionic silver was an effective sterilant of water containing the much more abundant coliform sewage organisms (Drake, Elgie and Walters, 1971) and the emergence of more resistant infecting strains of bacteria under conditions which preclude the use of the more usual sterilising agents, suggested an assessment of the efficacy of ionic silver against the *Pseudo-*

monas. Drake *et al.* (1971) described the Electrokatadyn Steriliser unit in their paper but, briefly, sterilisation is effected by electrolytic liberation into the infected water of silver ions in regulated minute amounts from a silver electrode.

Silver appears to exert anti-bacterial action in three ways which are almost unrelated. Metallic silver has a powerful oligodynamic action which may bring about the destruction of micro-organisms when only traces of silver are present. The simple salts ionise to liberate silver ions which are protoplasmic poisons, and colloidal silver preparations ionise only slightly and are mild antiseptics rather than powerful germicides (McCulloch, 1945).

Temperature has been found to exert an influence on the action of silver, the velocity of sterilisation being increased as the temperature was raised (Taylor, 1958). In the region of 0°C the bactericidal activity was insignificant in 24 hours and became too slow therefore for practical application. Aeration assists sterilisation by silver, and oxygen appears to play an important part in the process.

Comparison of sensitivity of Pseudomonas and Coliform bacilli to silver

In the laboratory, water containing 0·02 ppm of ionic silver was infected with the *Pseudomonas* organisms to give a concentration of 1×10^4 per millilitre. A second sample of the silver treated water was dosed with a similar number of *coliform* bacteria known to be sensitive to the metal, as a control. Samples of the two infected waters were withdrawn for culture at half-hourly intervals during eight hours of contact time with the silver ions, and again at 24 and 48 hours. These were inoculated on to nutrient agar culture plates which were then incubated at 37°C for 24 hours.

The minimum effective contact time for complete destruction of the infecting organisms at the silver concentration used, at 20°C, and with the stated inoculum dose, proved to be seven hours for the *Pseudomonas* and 3½ hours for the *Coliform bacilli.*

The effect of inoculum dose on sensitivity

The test was repeated using far greater numbers of the *Pseudomonas* and *Coliforms* (2×10^6 per ml) with the same concentration of silver (0·02 ppm), at an ambient temperature of 20°C.

A marked drop in the number of viable *Pseudomonas bacilli* was observed during the first six hours of contact with the silver impregnated water and this was followed by a steady increase until, at 48 hours, the concentration of live organisms had reached 5×10^3 per ml. The *coliforms* however, were as sensitive to silver as at the lower inoculum dose of 1×10^4 per ml.

The test was again carried out with the Pseudomonas, using a comparatively small inoculum to give a water concentration of 3×10^3 per ml. It was observed that complete destruction had occurred after only four hours contact with the silver impregnated water (Fig. 1).

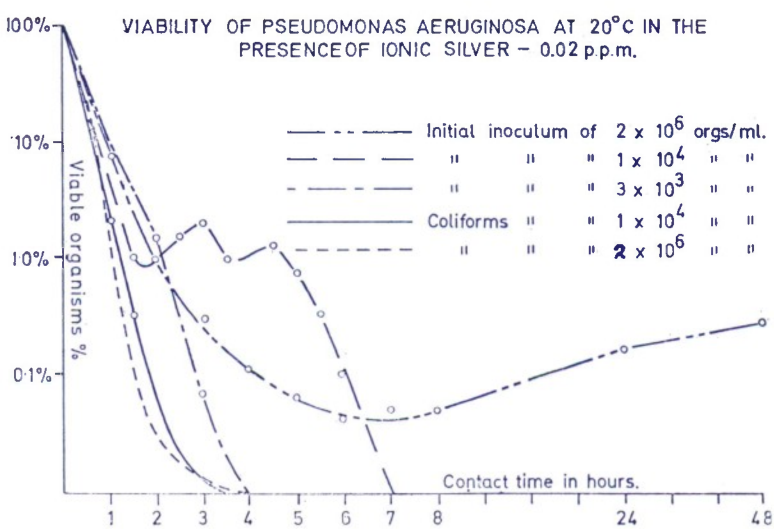

FIG. 1. Viability graph.

The effect of temperature on sensitivity

To determine the effect of temperature on the destructive properties of ionic silver, three separate 250 millilitre amounts of silver impregnated water were infected in equal small doses (2×10^3) of the *Pseudomonas,* and held at 20°, 27° 37°C. Samples were withdrawn from each at ½ hourly intervals, inoculated on to culture plates and incubated at 37°C for 24 hours. The effective contact times for complete destruction of the organisms at the different temperatures were noted and over this limited range there was no appreciable difference in the destructive effect of the silver.

The effect of increasing the silver concentration

Three water samples containing 0·1 ppm of ionic silver, a much higher concentration than that used in the previous investigations, were infected with *Pseudomonas* in doses equating with 3×10^3, 1×10^4, and 2×10^6 organisms per millilitre. The samples were kept at ambient temperature (20°C) and 0·1 ml amounts were withdrawn at regular intervals, inoculated on to culture plates and incubated for 24 hours at 37°C. At this concentration of silver, even the heavily infected sample containing 2×10^6 organisms per ml demonstrated no viable *bacilli* after six hours contact time (Table 1).

TABLE I.
Viability of Pseudomonas Aeruginosa at 20°C in the presence of 0·1 ppm Ionic Silver in Water.

Contact time (hours)		*Organisms per millilitre*	
0	3,000	10,000	2,000,000
½	320	1,000	—
1	40	110	60,000
1½	4	10	—
2	Nil	Nil	17,000
2½	Nil	Nil	12,000
3	Nil	Nil	7,000
4	Nil	Nil	2,880
5	Nil	Nil	550
6	Nil	Nil	Nil
7	Nil	Nil	Nil
8	Nil	Nil	Nil

Discussion

Pseudomonas aeruginosa is widely distributed in nature, and is sometimes found in the bowel and on the skin of man. It is a fairly common contaminant, but its chief importance is as a secondary invader in infected wounds, and suppurative conditions of the middle ear and urinary tract. This organism is most difficult to eradicate from lesions, being resistant to sulphonamides and most antibiotics. It can adapt itself to survive in strong solutions of certain hospital disinfectants and antiseptics. The porous cork of a disinfectant bottle is very liable to encourage the development of such resistance, presumably because it affords a gradation of concentration.

These organisms appear to be more chlorine-resistant than *coliform bacilli,* as Poynter and Mead (1964) found them readily in river-derived filtered water after normal works chlorination. In certain containment areas, particularly in diving chambers under pressure, where chlorine is precluded, the presence of *Pseudomonas aeruginosa* can provide a high risk of infection, primarily to the ears.

Although much has been written of the sensitivity or resistance of this bacillus to chemicals, disinfectants and antibiotics, no specific reference in the literature has been found regarding the effects of ionic silver.

The oligodynamic action of silver has been known for centuries, as King Cyrus used silver vases to bring water with him from the river Choaspes during his campaigns. Krause drew attention to the bactericidal properties of this metal and, in 1929, he introduced an activated form of silver and suggested its use for sterilising water supplies.

Laboratory investigations at the Institute of Naval Medicine demonstrated that some of the *Pseudomonas bacilli,* when present in water in great numbers, survived the effect of 0·02 ppm of silver. Many cations combine with proteins to form an insoluble albuminate (Wilson and Miles, 1966), hence this type of interference by the silver with the enzymatic structure of the *bacilli* would diminish the concentration of the silver ions available for a large population of bacteria.

The experiments proved that the ability of silver ions to effectively destroy *Pseudonomas aeruginosa* is not only dependent upon the amount of silver available in association with the correct contact time, but also to a great extent upon the number of infecting organisms present. Silver in a concentration of 0·02 ppm will effectively sterilise water containing 1×10^4 bacilli per ml after a contact time of seven hours. By increasing the organism population above 1×10^4 per ml, the probability of survival of the more resistant bacteria and subsequent growth is also increased, but the survival due to population density was overcome by an increase in the silver ion concentration.

Using the lower concentration of infection (1×10^4) of *Coliform* and *Pseudomonas* bacteria, the effective contact time for complete destruction of the latter organism was just twice that required for the control. *Pseudomonas aeruginosa* does therefore demonstrate a certain resistance to sterilisation by ionic silver as it does to other chemicals and antibiotics.

In swimming baths and diving chambers, these infecting organisms isolated in routine quality control of the water, have been found to be numbered in hundreds per ml rather than the high doses used in laboratory tests, and it has been shown that ionic silver is efficient against a low density population. Silver has no vapour pressure and thus prolonged storage of the silver sterilised water will not reduce its germicidal properties, although this effect would, in practice, be limited by the rate of adsorption of silver on the surface with which the treated water comes in contact.

Conclusion

Laboratory investigations of the sterilising efficiency of ionic silver against the particularly resistant *Pseudomonas* species, provide evidence that the Electrokatadyn Unit could be employed to good effect in practical water sterilisation where the use of chlorine is contra-indicated.

Acknowedgments

Our thanks are given to the Medical Director General (Naval), Surgeon Vice Admiral Sir Eric Bradbury and the Medical Officer-in-Charge, Institute of Naval Medicine, Surgeon Rear Admiral J. Watt, for permission to publish this article.

Thanks are also offered to Lieutenant Commander R. N. Jackson, RNES, of the Admiralty Distilling Experimental Station, Portland, for the use of a Katadyn unit for these investigations.

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SHAPING TOMORROW'S WARSHIPS— AEW CENTENARY OPEN DAYS

D. K. Brown, M.Eng., C.Eng., F.R.I.N.A., R.C.N.C.

Admiralty Experiment Works

FIG. 1. Reception area with photographs of one typical ship from each decade in the life of AEW.

The Admiralty Experiment Works celebrated its centenary in April 1972 by a series of open days in which displays and demonstrations showed past achievements and present activities.

The aim of AEW is to evolve hull forms which move through the water economically, silently and with a minimum of vibration and of motion in rough seas. The forms chosen must also be controllable; a three dimensional problem for submarines.

The open day displays took these themes under the headings of Speed, Stealth (Fig. 3), Seakeeping, and Steering (Fig. 4).

Further exhibits showed the history of AEW. For visual impact, the static displays which illustrated the background to the work of AEW took second place to the following demonstrations of experimental techniques.

FIG. 2. Shapes of ships are chosen to suit their functions.

No. 1 Ship Tank—Measurement of slamming impact pressures on the bottom of a frigate moving through waves.

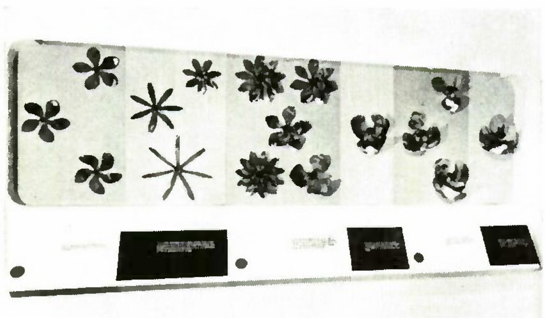

FIG. 3. A range of experimental propellers tried after World War II.

No. 2 Ship Tank—An experiment to measure the interaction between hull and propeller on a submarine.

Cavitation Tunnels—Cavitation on propellers in uniform flow and in association with a model ship.

Circulating Water Channel—Flow, ventilation and cavitation around the appendages of a frigate.

Manoeuvring Tank—Manoeuvring of a frigate in calm water and in rough seas. Control of a submerged submarine. Forces on the hull of a containership *(Tokyo Bay)* while turning (using the Rotating Arm). Roll Stabilisation by a passive flume tank.

All workshops and laboratories were open to visitors.

FIG. 4. Stern shapes and rudders are designed to meet the needs of each ship.

FIG. 5. Mr. Ian Gilmour (Minister of State for Defence Procurement) with the Superintendent (Mr. A. J. Vosper, RCNC) studying a portrait of our founder, William Froude.

Distinguished visitors included Mr. Ian Gilmour (Minister of State for Defence Procurement, Fig. 5), leaders of the shipbuilding and ship owning industries, local dignatories, academic staff, ship tank superintendents from all over Europe as well as senior staff from the Ministry of Defence. Several coach loads of staff came from Ship Department Bath and schools, colleges and apprentice training centres were represented by both staff and pupils.

The history of AEW and its current activities were well covered on television and, rather less accurately, by the Press. Southern Television made a point of introducing its broadcast from H.M.S. *Victory*. the only ship in the Royal Navy not tested at AEW.

The Royal Institution of Naval Architects concluded its Spring Meeting with a visit to AEW during which a paper was discussed in the morning leaving the afternoon free for Fellows and Members to tour the exhibits (Fig. 6).

FIG. 6. The President, Sir A. J. Sims, Fellows and Members of the RINA at AEW.

Saturday was a happy, if chaotic, day in which some 2,000 friends and relations of the staff together with former employees squeeezed themselves into the Establishment.

The preparation of the display material was not without value to the staff since it forced research workers to think deeply and clearly about the purpose of their work and what it achieves. Without exception, AEW staff found that they had a lot to learn about the activities of their Establishment.

Open day preparations involve a great deal of hard work and the co-operation of many MOD and outside organisations. To carry out this work without interrupting the normal experiment programme, demanded the utmost enthusiasm and co-operation from the staff. Over 20 organisations assisted in the preparation but special mention must be made of Messrs. Mutimer and Colberg of MTIP(N) who designed the display material and of ASWE who lent so much material prepared for their own open days and were always willing to help us with advice.

A.M.L. OIL SLICK SKIMMER

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Michael Freegarde joined the R.N.S.S. as a Scientific Officer at Bragg Laboratory, Sheffield in 1956 after obtaining a B.Sc.(Hons.) in Chemistry and A.R.I.C. He carried out research into new methods for the analysis of steels and non-ferrous alloys, and was promoted to Senior Scientific Officer in 1962. He transferred to A.M.L. in 1966 and was promoted to Principal Scientific Officer in 1969. At present he is Head of the Inorganic and Physical Chemistry Section and is engaged on the application of sensitive analytical techniques to a variety of naval problems.

Research has been carried out at AML aimed at meeting the need for helicopter-borne equipment for use in SUBMISS/SUBSUNK operations to differentiate between oils that could have been released by a submarine and oils from other sources. In the course of this work, the principle of using a vortex to concentrate oil from a thin slick on the sea was discovered as a means of sample collection. The basic idea is that if water with oil on the surface is stirred, a vortex forms into which the oil drains. A slick sampler incorporating this principle[1] was built and is part of the kit that has been recommended to meet the Navy's need.

Thoughts naturally turned to ways in which the principle might be applied in scaled-up versions for collecting, as opposed to sampling, oil slicks. An attractive idea was to use the forward motion of an open-fronted vessel to drive the oil and water tangentially into a circular chamber to induce circular motion and separation[2] (Fig. 1). The clearance unit could either be self-propelled or in the form of pods boomed out from any convenient vessel (Fig. 2). It was proposed to construct a working model purely to demonstrate the principle and, as this went beyond the Navy's interests, the construction was carried out at AML under repayment by Warren Spring Laboratory (DTI), who are responsible for most aspects of oil clearance research.

The general layout of the skimmer is shown in Fig. 3. Two counteracting clearance units were included because if only one were used, the vessel would move crabwise. A small motor-driven paddle is provided in each clearance unit to sharpen the vortex and encourage oil collection. Fig. 4 shows how the oil is separated. Oil rises within the rotating inner tube and is thrown out through holes into an attached annular trough from whence it is pumped into a storage bottle. The skimmer has been tested at Portsmouth. The speed is slow but the collection effective. Further development is required before the degree to which the device may be scaled-up can be predicted and its final status in the armoury of oil clearance techniques assessed.

References

[1] British Patent 1212222. [2] British Patent 1274387.

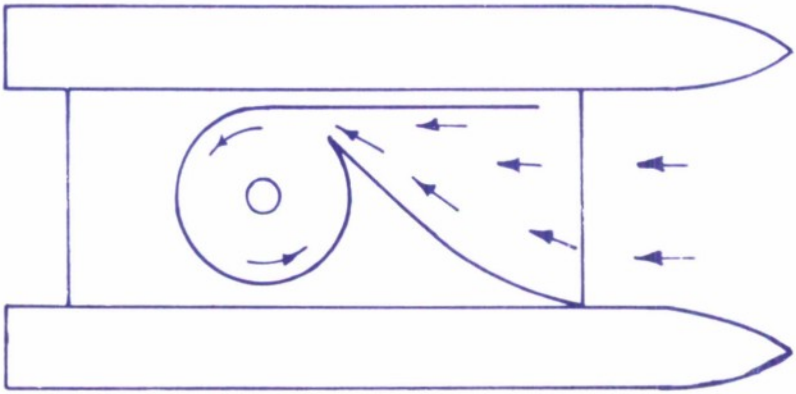

FIG. 1. Principle of oil slick skimmer.

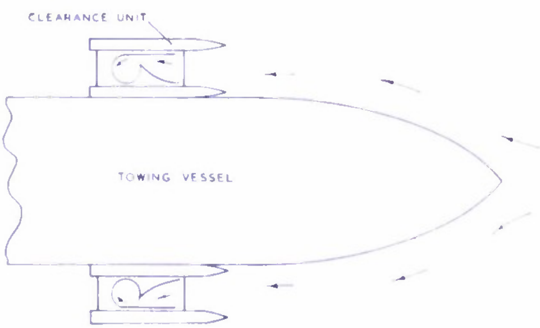

FIG. 2. Arrangement using towed clearance pods.

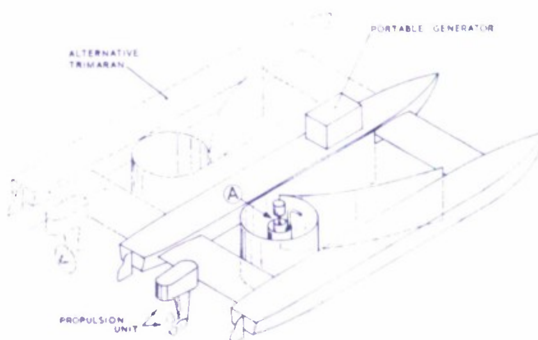

FIG. 3. General layout of prototype skimmer.

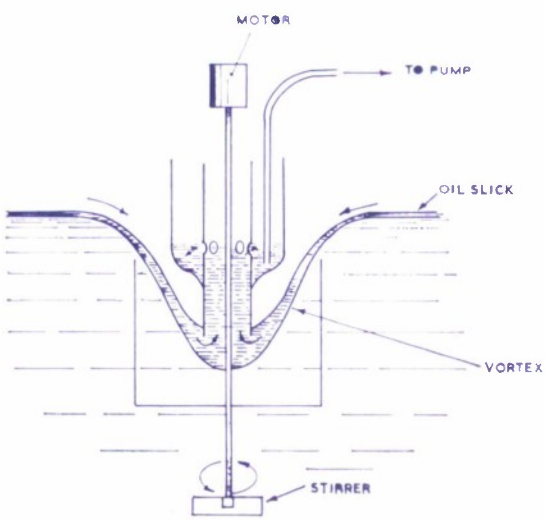

FIG. 4. Separation and collection of oil.

DESIGN CONSIDERATIONS FOR OPTIMUM SHIP MOTION CONTROL

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Admiralty Engineering Laboratory

Abstract

The control of ship's motion in roll and yaw has traditionally been treated as two independent control problems but it is possible for a significant cross-couple to exist between these two modes of motion. This article discusses the implication of cross-couple between steering and roll stabilising and considers the possibility of an integrated ship motion control system. Integrated control would enable an optinal ship motion policy to be adopted to achieve minimum roll or minimum yaw, as required, to meet the ship's operational needs.

Introduction

A ship and its associated motion control systems can be considered as a complete system designed specifically to accomplish certain operational requirements. The efficiency with which these operational requirements are met depends on the satisfactory operation of individual sub-systems such as propulsion, steering and roll stabilising. If the system as a whole is to operate efficiently, it is important that each sub-system operates in a manner which augments the performance of the complete system and, if possible, in some appropriate optimal fashion.

Ship motion control divides into three facets —the propulsion system, the steering system and the roll stabiliser system. Current practice is to design each of these exclusive systems to achieve a best performance on the assumption that there is no interaction between them, *i.e.* each is statically and dynamically independent of the others. Due to the position and orientation of rudder and stabiliser fins in some ship designs, there exists a significant cross-couple between roll and yaw and consequently a best individual performance criterion for each sub-system will not guarantee a best performance from a total ship motion control standpoint. If these exclusive control systems were replaced by a multivariable system, then cross-couple and interaction between roll and yaw would be taken into account and an optimised total ship motion performance could be realised.

To adopt a total ship motion policy, operational requirements must be defined in terms of acceptable modes of motion for particular operations in order to organise the control system to permit optimisation of a particular ship motion. For example, optimised yaw for fuel economy, replenishment at sea or precise course keeping, optimised roll for aircraft operation and restrained rudder angles, fin angles and ship's speed for reduced underwater noise propagation.

If, due to hull design restraints, control surfaces are positioned such that stabiliser fin and rudder forces interact, then it would appear that consideration should be given to multivariable control as a means of achieving a total ship motion control as a future control philosophy. Alternatively, should multivariable control be considered impractical, due to its complexity, then other methods of generating motion control forces should be considered. Whatever the solution adopted to minimise the adverse effects of cross-couple, it is important that the motion control problems be considered from a systems approach, *i.e.* given the ship's operational requirements, design the ship's hull and associated control forces to achieve the desired operational requirements in the most efficient manner.

Ship Motion Control Using Active Control Surfaces

The externally applied forces and moments employed to control ship motion are generally derived from the propeller, the rudder and the stabiliser fins. This article is confined to considering the influence of the rudder and stabiliser fins. The position and orientation of active control surfaces determines the nature of the forces and the moments generated. However, practical design considerations often prevent freedom of choice of the position and orientation of control surfaces.

Fig. 1 illustrates the axis system used in the analysis. Fig.2 is a schematic of the hydro-

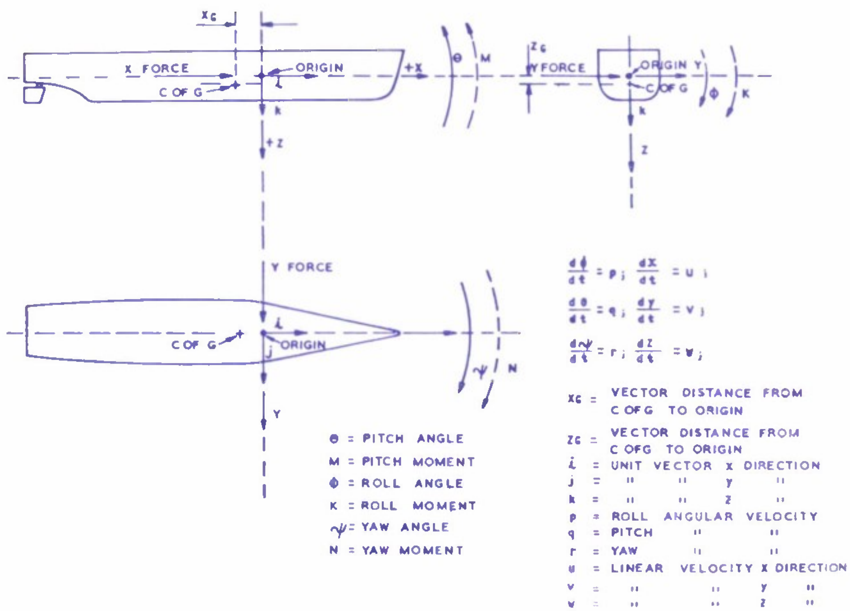


FIG. 1. Axis system.

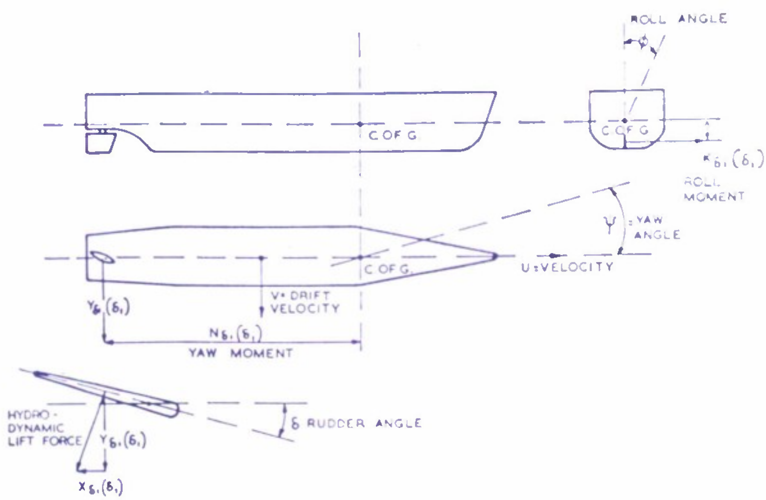


FIG. 2.
Forces and moments generated by rudder.

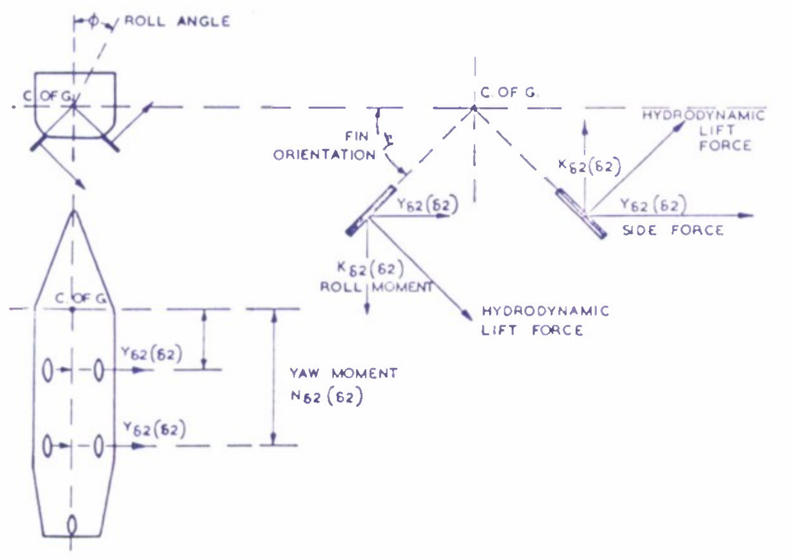


FIG. 3.
Forces and moments generated by stabiliser fins.

dynamic forces produced by a ship's rudder. The hydrodynamic lift, acting at the centre of pressure, develops two significant moments, firstly a yaw $N_{\delta_1}(\delta_1)$ and secondly a roll moment $K_{\delta_1}(\delta_1)$. In addition a side force $Y_{\delta_1}(\delta_1)$ is developed which contributes to both roll and yaw moments. It is apparent, therefore, that yaw control using a conventional rudder system involves coupled excitation of yaw and roll.

Fig. 3 shows typical positioning and orientation of a stabiliser fin installation in which the active fins operate in a push-pull mode. The orientation of the fins causes both a roll moment $K_{\delta_2}(\delta_2)$ and a yaw moment $N_{\delta_2}(\delta_2)$ to be generated. In addition, a side force $Y_{\delta_2}(\delta_2)$ is produced and this contributes to both roll and yaw moments. It is again shown that roll control using stabiliser fins, orientated at any angle other than horizontal, will generate coupled excitation of both yaw and roll.

Equations of motion

Appendix I shows that the simplified linearised equations for ship motion in yaw and roll can be written:

$$\left[(Y_{\dot{v}} - m)s + Y_v\right] V + (Y_r - mu_o)r = Y_{\delta_1}(\delta_1) + Y_{\delta_2}(\delta_2) \qquad \ldots (1)$$

$$(N_v)v + \left[(N_{\dot{r}} - I_z)s + N_r\right]r = N_{\delta_1}(\delta_1) + N_{\delta_2}(\delta_2) \qquad \ldots (2)$$

$$(K_v)v + (K_r)r + \left[(K_{\dot{p}} - I_x)s + K_p + \frac{K_\phi}{s}\right] p = K_{\delta_1}(\delta_1) + K_{\delta_2}(\delta_2) \qquad \ldots (3)$$

Free Motion of Ship

Consider the case of no externally applied forces, *i.e.* the RHS of equations 1, 2 and 3 equal zero. The remaining homogeneous equations are then the characteristic equations representing the ship dynamics.

If either the drift velocity (v) or the yaw angular velocity (r) are different from zero and $-K_v(v) \neq K_r(r)$ then there must also be a roll angular velocity (p) (from equation (3)). Hence a coupling exists between yaw and roll.

Alternatively, if only a roll angle $\phi = {}^{p}/_{s}$ exists then subsequent free motion will not excite yaw or drift motions. Hence free roll motion is independent of yaw and drift.

The above argument is the basis for considering the roll motion and therefore the stabilising problem of ships to be a single degree of freedom analysis. However, this argument must be extended to include the forced motion solution of the equations and therefore consideration given to the coupling characteristics of the externally applied forcing terms.

Interaction between Steering and Stabilising

Although pure roll motion of a ship is independent of yaw and drift and can be viewed as a single degree of freedom system, the problem of controlling roll motion by active anti-roll fins extends the problem to a three degrees of freedom situation and thereby involves considering the interaction between steering and stabilising.

To appreciate more clearly the nature of the interaction between steering and stabilising, equations (1), (2) and (3) are reduced to a pair of simultaneous equations with independent variables (p) and (r).

As shown in Appendix I, the equations of motion for yaw and roll can then be written:

$$r = [N_{\delta_1}(\delta_1) + N_{\delta_2}(\delta_2)]\, K_2(s+b) - K_4[Y_{\delta_1}(\delta_1) + Y_{\delta_2}(\delta_2)]\, \frac{K_1}{(s^2+fs+g)} \qquad \ldots (4)$$

$$p = \left\{K_{\delta_1}(\delta_1) + K_{\delta_2}(\delta_2) - \frac{\left[Y_{\delta_1}(\delta_1) + Y_{\delta_2}(\delta_2)\right]K_3}{(s+b)} - K_5\frac{(s+a)r}{(s+b)}\right\} \times \frac{K_6}{\left[s^2 + 2\zeta\omega_n s + \omega_n^2\right]} \qquad \ldots (5)$$

A schematic representation of equations (4) and (5) is shown in Fig. 4; this indicates more clearly the interactions between steering and stabilising.

Steering System

Fig. 4 shows that ship motion control using only the rudder system induces two modes of motion, *i.e.* yaw and roll. Consider firstly the roll moments, the rudder develops two opposed rolling moments, one acts directly as a roll moment K_{δ_1} while the second is dependent on the yaw rate (r) and is therefore delayed due to the yaw response characteristic but acts in opposition to the direct moment. This is well known and results in the heel angle of a ship changing from inwards to outwards as the ship initiates a turn manoeuvre. A secondary moment is developed from the side thrust of the rudder which contributes to both roll and yaw. This roll moment acts in the same sense as that due to the yaw rate.

Stabiliser System

The control of roll motion by inclined active fins, suffers a detrimental coupling effect which is clearly indicated in Fig. 4. The principal roll moment K_{δ_2} is opposed by a moment derived from the yaw moment com-

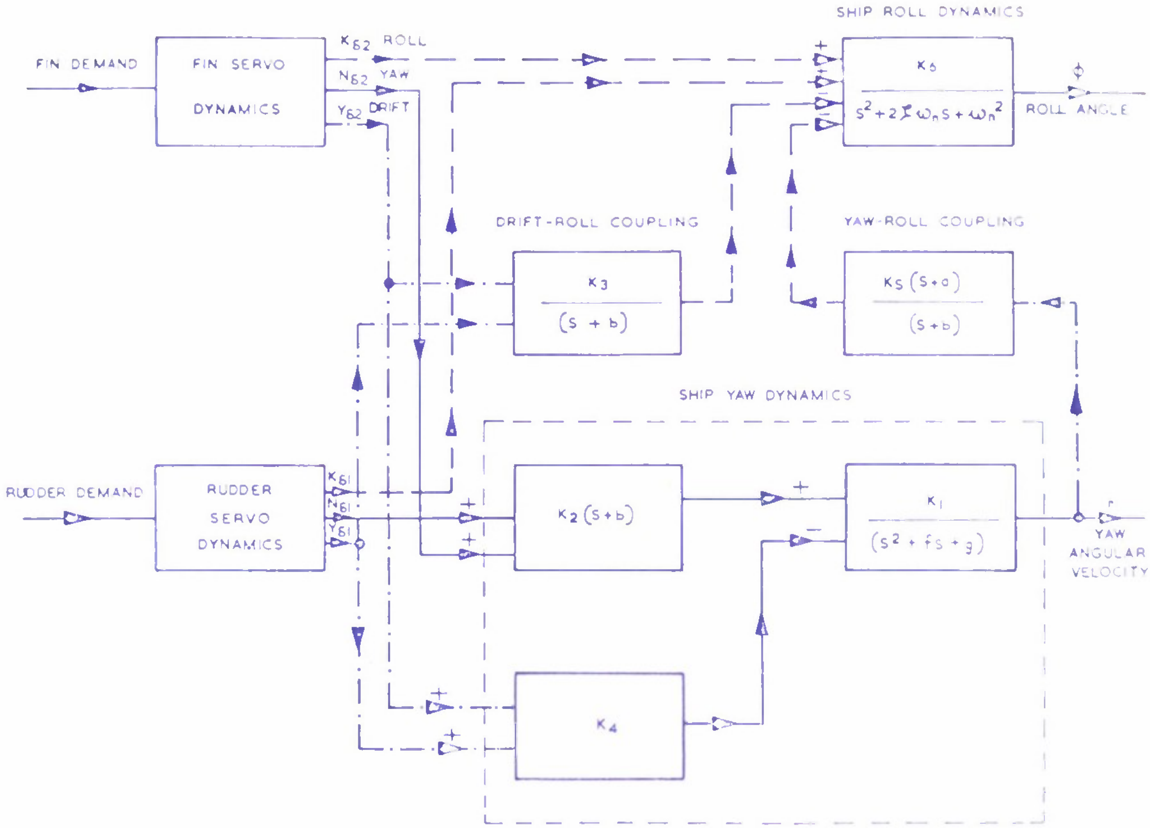


FIG. 4. Schematic of cross-coupling between steering and stabilising.

ponent of the fin forces and a secondary moment due to the side thrust component. As the opposing moment is dependent on the yaw dynamics, its effect on the direct roll moment will be frequency dependent, *i.e.* the magnitude of the resultant roll moment will be dependent on the relative magnitude and phase characteristics of the three components.

An important facet of this adverse coupling is that any attempt to measure the characteristics of active fins or of the ship in roll, using a force roll technique based on fin oscillation, will result in erroneous results if the subsequent analysis is based on a single degree of freedom ship model, *i.e.* pure roll dynamics. The three components comprising the resultant roll moment must be dynamically identified which necessitates consideration of the yaw dynamics and the fin position and orientation.

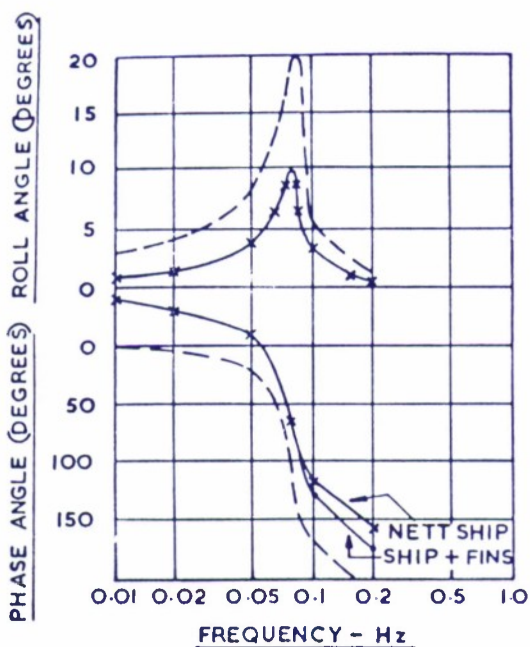
Ship Trial Results

Trials were carried out on a "Leander" frigate with the primary purpose of measuring the roll characteristics of the hull and the hydrodynamic lift of the fins. The significance of cross-couple between steering and stabilising did not become apparent until subsequent analysis of the trial results. The technique employed to measure the ship roll characteristics was to induce forced rolling, in calm water, by means of the stabiliser fins, at a variety of frequencies. The measurements of the phase relationship and roll magnitude of the ship with respect to the disturbing moment generated by the stabiliser fins, is shown graphically in Fig. 5.

The general shape of this ship response characteristic approximates to that of a second order lag, as would be expected, but considerable phase advance occurs at low frequencies (below 0·05Hz). This could not occur in a simple second order system and these results forced one to question the validity of the simple single degree of freedom model currently used to represent ship roll dynamics. This simple equation of motion is of the form:

$$\frac{\text{Roll angle } (\phi)}{\text{Disturbing moment } (M_f)} = \frac{K}{s^2 + 2\zeta\omega_n s + \omega_n^2} \quad \dots (6)$$

Applying simple rolling theory to the trial data, actual hydrodynamic fin lift was calculated and found to be considerably less than the expected value. Typical values for fin lift were 30% of expected value at d.c., 50% at ship natural frequency and 70% at twice natural frequency. The broken line on Fig. 5 shows the simulated forced roll performance assuming that ship roll characteristics can be represented by a single degree of freedom model (Equation 6) and that fin hydrodynamic lift is ideal and equal in performance to model fins tested in a cavitation tunnel. Comparing experimental ship roll response with the simulated response, assuming a single degree of freedom and ideal fin lift coefficient, it is evident that the apparent fin lift deduced from experimental results will appear less than ideal and frequency dependent. Furthermore, owing

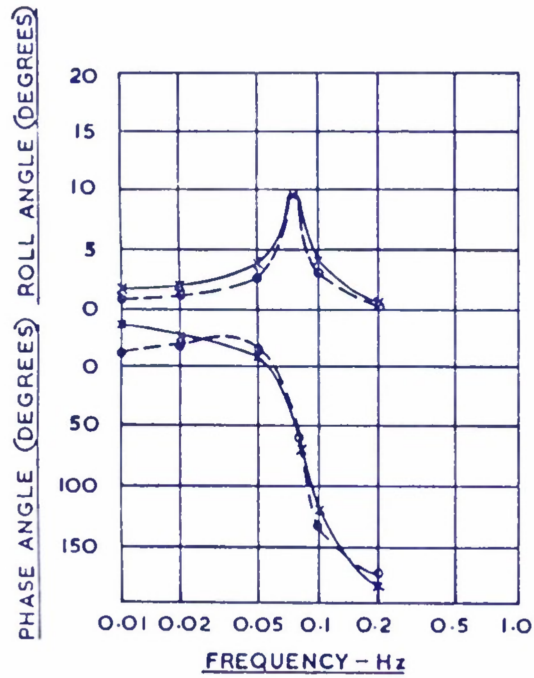


Ship trials data x—x—x
Ship speed 19 knots
Fin angle ± 15° harmonic oscillation

Simulated ship response assuming single degree of freedom ship model and ideal fin lift — — — —
Ship speed 19 knots
Fin angle ± 15° harmonic oscillation

FIG. 5. Comparison of trials data and single degree of freedom simulation to forced rolling.

to cross-coupling the Q factor or damping constant ζ cannot be estimated from the magnitude of the resonant peak, *i.e.*



Ship trials data x—x—x
Ship speed 19 knots
Fin angle ± 15° harmonic oscillation

Simulated ship response assuming three degree of freedom ship model and ideal fin lift o— —o— —o
Ship speed 19 knots
Fin angle ± 15° harmonic oscillation

FIG. 6. Comparison of trials data and three degree of freedom simulation to forced rolling.

$$M = \frac{1}{2\zeta\sqrt{(1 - \zeta^2)}} \quad \dots (7)$$

where M = magnification factor at resonance.

An estimate of the damping factor, based on the above expression, will in fact be approximately half the true value.

From these experimental results it can be concluded that:

(1.) Stabiliser fins on some ships, depending on fin position and orientation, generate significant yaw moments in addition to roll moments.

(2.) Attempts to measure hydrodynamic fin lift by forced rolling techniques, results in very low values for apparent fin lift. Actual hydrodynamic fin lift is masked by yaw-roll cross-coupling.

(3.) Ship roll dynamics can only be measured by forced rolling techniques if the fin yaw-roll cross-coupling dynamics are known and taken into account.

(4.) Ship rolling dynamics cannot be adequately represented by a single degree of freedom model, except under free roll conditions.

(5.) Ship damping factor ζ must be evaluated from a free roll decay period and not from frequency response studies unless the yaw-roll cross-coupling is fully identified dynamically.

Three Degree of Freedom Model

To confirm the effect of the yaw-roll coupling of the stabiliser fins on the force roll response of the ship, a simple analogue simulation of the ship using equations (1), (2) and (3) was developed.

Fig. 6 shows the response of the ship equation to forced rolling by the fins using a $\pm$ 15° harmonic oscillation. It is clear that the behaviour computed from the three degrees of freedom model produces a closer approximation to the trial results than the single degree of freedom model.

Also the simulation showed that, although the magnitude of the yaw oscillation induced by the fins at the ship's roll natural frequency is small, the roll moments associated with the yaw motion is approximately half the direct roll moment produced by the fins. Consequently its effect on the performance of the stabiliser system is very significant. This is because the basic characteristic of anti-roll systems is based on damping and not force control, *i.e.* the roll inertia of the ship is too large to permit effective roll reduction by applying a compensating force. Consequently stabiliser systems utilise the Q factor of ships to advantage by applying a small magnitude damping force to reduce the resonant response of the ship. As a result, the damping moment developed by the anti-roll fins and the roll moment introduced by the yaw motion of the ship are of the same order of magnitude and therefore tend to cancel each other.

Conclusions

The basic concept of ship motion control discussed in this article, was derived as a consequence of evaluating the operational performance of a conventional active stabiliser system. The ship trial was the first serious and successful attempt to quantify the effect of active anti-roll fins on the roll behaviour of a ship by harmonic force rolling. The results obtained inevitably lead one to examine and question the usefulness of hydrofoil type anti-roll systems.

To achieve the optimum from a ship in terms of motion control, the total motion control problem, *i.e.* propulsion, steering and stabilising, should be considered as a complete system. A consequence of not considering the systems approach is the situation discussed in this article in which, owing to the position and orientation of the conventional control surfaces, both steering and stabilising systems exhibit a significant dynamic coupling which appreciably impairs the effectiveness of each control system, *i.e.* each system expends part of its energy in counteracting the forces generated by the other.

To obtain the optimum performance from a ship motion control system, whether active or passive, the dynamic response characteristics of the proposed hull, together with any control surfaces, should be evaluated. This data would permit computer simulation studies of the ship system to indicate what total motion control system could be designed to exploit the best possible overall performance.

Such studies could reveal that if severe restrictions exist on the position and orientation of certain control surfaces, *i.e.* inclined positioning of stabiliser fins, then the consequence of this design restriction must be fully evaluated as introduction of such a system may be inefficient in itself and also significantly impair the performance of another system, *i.e.* steering. It is feasible that a hetter overall performance could be realised hy employing a passive stabiliser system which may provide as much stabilisation as an inefficient active system and not impair the performance of the steering system.

If a passive anti-roll system cannot provide sufficient roll damping then the design of a suitable active system must attempt to minimise cross-coupling effects within the restraints imposed by the overall hull design. If, however, active stabiliser fins are used and significant dynamic coupling is present, then a multivariable control system should be considered. This would sense errors in roll angle and yaw, take account of cross-coupling effects, and computer the optimum stabiliser and rudder demand signals.

The multivariable concept permits greater flexibility in the system design to ensure the total system provides the best possible control for specific operational requirements. Design concepts are being considered which comprise three alternative manually selective policies.

(1.) A nominal cruise policy designed to to minimise the energy loss due to interaction between yaw and roll.

(2.) An operational policy to permit both steering and stabilising systems to be employed optimally together to reduce roll to a minimum to facilitate safe operation of aircraft in adverse weather conditions.

(3.) Both systems combined optimally to reduce yaw motion to a minimum, thus permitting precise course keeping for for replenishment at sea operations or stringent navigational requirements.

Ship's staff would be able to choose, therefore, how best to employ the available control forces to meet short term objectives.

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The views expressed in this paper represent the work of a small team at A.E.L who took part in ship trials and analysis of trial results. The suggestions and assistance of Mr. K. W. Hammond were particularly valuable and are gratefully acknowledged.

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Notation

i j k	unit vectors x, y and z directions respectively
I_x I_y I_z	moments of inertia of vessel about x, y and z axes respectively
K M N	externally applied moment about x, y and z axes respectively
m	mass of vessel
n	angular velocity of propeller shaft
p	roll angular velocity
q	pitching angular velocity
r	yawing angular velocity
s	Laplace operator
u	ship speed
U_0	steady state ship speed
v	drift velocity
w	slamming velocity
X Y Z	externally applied forces in x, y and z directions respectively
X_G Y_G Z_G	vector distance of C of G from origin
X_0 Y_0 Z_0	translational motion relative to geographically fixed axes
ωn	ships natural roll angular frequency
ζ	ships damping factor in roll
ϕ	roll angle
ψ	yaw angle
δ	rudder angle

All derivative functions are expressed in abbreviated notation as follows:—

$$K_v \equiv \frac{\partial k}{\partial v}; \qquad Y_v \equiv \frac{\partial Y}{\partial v}$$

$$\dot{u} = \frac{du}{dt}; \qquad \dot{v} = \frac{dv}{dt} \quad \text{etc.}$$

APPENDIX I

Equations of Motion for Ship

The equations of motion are derived from the theorem of moving axes in which a set of rectangular axes is employed with an origin fixed in and moving with the vehicle but not coincident with the centre of gravity of the vehicle. To simplify the form of the equations the axis system is chosen to be parallel to the principal axes of inertia.

The vector distance of the C of G from the origin is, $R_G = iX_G + jY_G + kZ_G$. The axis system is depicted pictorially in Fig. 1, the corresponding equations of motion are,

$$X = m\,[\dot{u} + qw - rv - X_G(q^2 + r^2) + Y_G(pq - \dot{r}) + Z_G(pr + \dot{q})]$$

$$Y = m\,[\dot{v} + ru - pw - Y_G(r^2 + p^2) + Z_G(qr - \dot{p}) + X_G(qp + \dot{r})]$$

$$Z = m\,[\dot{w} + pv - qu - Z_G(p^2 + q^2) + X_G(rp - \dot{q}) + Y_G(rq + \dot{p})]$$

$$K = I_x\dot{p} + (I_Z - I_Y)qr + m\,[Y_G(\dot{w} + pv - qu) - Z_G(\dot{v} + ru - pw)]$$

$$M = I_y\dot{q} + (I_x - I_z)rp + m\,[Z_G(\dot{u} + qw - rv) - X_G(\dot{w} + pv - qu)]$$

$$N = I_Z\dot{r} + (I_y - I_x)pq + m\,[X_G(\dot{v} + ru - pw) - Y_G(\dot{u} + qw - rv)]$$

... (1a)

The terms u, v, w, p, q, and r represent the acceleration components within the moving axis system. The additional terms (qw-rv), (ru-pw), (pv-qu), qr, rp, pq arise from the moving co-ordinate system and represent the components of centripetal accelerations. All the remaining terms involving the co-ordinates of the C of G describe the centrifugal and reaction forces and the moments acting at the origin due to the acceleration of the C of G relative to the origin.

Consider motion in the horizontal plane with rolling and invoking the following assumptions,

(a) the origin of the rectangular axis system is on the line of lateral symmetry going through the C of G *i.e.* $Y_G = O$.

(b) no pitching motion *i.e.* $q = w = M = O$. Equations (1) then reduces to:

$$X = m\,[\dot{u} - rv - X_G r^2 + Z_G pr]$$

$$Y = m\,[\dot{v} + ru + X_G\dot{r} - Z_G\dot{p}] \qquad \text{... (2a)}$$

$$N = I_Z\dot{r} + mX_G(\dot{v} + ru)$$

$$K = I_x\dot{p} - mZ_G(\dot{v} + ru)$$

To obtain the complete solution of equations (2a) it is necessary to express the force and moment terms X, Y, N and K in a useful mathematical form. Provided the force terms X, Y, N and K are continuous functions of a set of independent variables and their derivatives then the Taylor expansion can be employed to express X, Y, N and K in a precise mathematical form.

Hence assuming

$$\begin{matrix} X \\ Y \\ N \\ K \end{matrix} = f\left\{ x_o y_o \phi\psi \;\; uvpr \;\; \dot{u}\dot{v}\dot{p}\dot{r} \;\; \delta\dot{\delta} \;\; n \;\; \dot{n} \right\}$$

and retaining only the linear terms in the expansion gives,

$$X = X_{x_o} x_o + X_{y_o} + X_\phi\phi + X_\psi\psi + X_u\Delta u + X_v v + X_p p + X_r r$$
$$+ X_{\dot{u}}\dot{u} + X_{\dot{v}}\dot{v} + X_{\dot{p}}\dot{p} + X_{\dot{r}}\dot{r} + X_\delta\delta + X_{\dot{\delta}}\dot{\delta} + X_n n + X_{\dot{n}}\dot{n}$$

$$Y = Y_{x_o} x_o + Y_{y_o} y_o + Y_\phi\phi + Y_\psi\psi + Y_u\Delta u + Y_v v + Y_p p + Y_r r + Y_{\dot{u}}\dot{u}$$
$$+ Y_{\dot{v}}\dot{v} + Y_{\dot{p}}\dot{p} + Y_{\dot{r}}\dot{r} + Y_\delta\delta + Y_{\dot{\delta}}\dot{\delta} + Y_n n + Y_{\dot{n}}\dot{n} \qquad \text{... (3a)}$$

$$K = K_{x_o} x_o + K_{y_o} y_o + K_\phi\phi + K_\psi\psi + K_u\Delta u + K_v v + K_p p$$
$$+ K_r r + K_{\dot{u}}\dot{u} + K_{\dot{v}}\dot{v} + K_{\dot{p}}\dot{p} + K_{\dot{r}}\dot{r} + K_\delta\delta + K_{\dot{\delta}}\dot{\delta} + K_n n + K_{\dot{n}}\dot{n}$$

$$N = N_{x_o} x_o + N_{y_o} y_o + N_\phi\phi + N_\psi\psi + N_u\Delta u + N_v v + N_p p + N_r r$$
$$+ N_{\dot{u}}\dot{u} + N_{\dot{v}}\dot{v} + N_{\dot{p}}\dot{p} + N_{\dot{r}}\dot{r} + N_\delta\delta + N_{\dot{\delta}}\dot{\delta} + N_n n + N_{\dot{n}}\dot{n}$$

It can be shown (1) that based on the following assumptions,

(a) a change in orientation of the ship in yaw does not create forces,

(b) ship motion is in a straight line and incurs only small deviations from course,

(c) the effects of the derivatives of the control surfaces and the propellers are negligible,

(d) linearising the equations of motion, eqn(2a), about steady state values *i.e.* small perturbations.

The equations of motion for yaw and pitch motion can be reduced to,

$$\overbrace{(X_{\dot{u}} - m)\,s}^{a11}u = + X_n n \qquad \text{... (4a)}$$

$$\overbrace{(Y_{\dot{u}}s + Y_u)}^{a12}u + \overbrace{\left[(Y_{\dot{v}} - m)s + Y_v\right]}^{a22}v + \overbrace{\left[(Y_{\dot{r}} - mX_G)s + (Y_r - mu_o)\right]}^{a23}r +$$
$$\overbrace{\left[(Y_{\dot{p}} + mZ_G)s + Y_p\right]}^{a24}p = Y_{\delta_1}(\delta_1) + Y_{\delta_2}(\delta_2)$$

... (5a)

$$\overbrace{(N_{\dot{u}}s + N_u)}^{a13}u + \overbrace{\left[(N_{\dot{v}} - mX_G)s + N_v\right]}^{a23}v + \overbrace{\left[(N_{\dot{r}} - I_Z)s + (N_r - mX_G\,u_o)\right]}^{a33}r +$$
$$\overbrace{(N_{\dot{p}}s + N_p)}^{a34}p = N_{\delta_1}(\delta_1) + N_{\delta_2}(\delta_2) \qquad \text{... (6a)}$$

$$\overbrace{(K_{\dot{u}}s + K_u)}^{a14}u + \overbrace{\left[(K_{\dot{v}} + mZ_G)s + K_v\right]}^{a24}v + \overbrace{\left[(K_{\dot{r}}s + (K_r + mZ_G u_o)\right]}^{a34}r +$$
$$\overbrace{\left[(K_{\dot{p}} - I_x)s + K_p + \frac{K_\phi}{s}\right]}^{a44}p = K_{\delta_1}(\delta_1) + K_{\delta_2}(\delta_2)$$

... (7a)

The above can be written in matrix form as,

$$\begin{bmatrix} a_{11} & 0 & 0 & 0 \\ a_{12} & a_{22} & a_{32} & a_{42} \\ a_{13} & a_{23} & a_{33} & a_{43} \\ a_{14} & a_{24} & a_{34} & a_{44} \end{bmatrix} \begin{bmatrix} u \\ v \\ r \\ p \end{bmatrix} = \begin{bmatrix} X_n & 0 & 0 \\ 0 & Y_{\delta_1} & Y_{\delta_2} \\ 0 & N_{\delta_1} & N_{\delta_2} \\ 0 & K_{\delta_1} & K_{\delta_2} \end{bmatrix} \begin{bmatrix} n \\ \delta_1 \\ \delta_2 \end{bmatrix} \quad \ldots (8a)$$

The equations are further simplified by retaining only the most significant terms. hence,

$$\overbrace{(X_{\dot{u}} - m)}^{a11} su = X_n n \quad \ldots (9a)$$

$$\overbrace{\left[(Y_{\dot{v}} - m)s + Y_v\right]}^{a22} v + \overbrace{(Y_r - mu_o)}^{a23} r = Y_{\delta_1}(\delta_1) + Y_{\delta_2}(\delta_2) \quad \ldots (10a)$$

$$\overbrace{\left[(N_{\dot{r}} - I_z)s + N_r\right]}^{a33} r + \overbrace{(N_v)}^{a32} v = N_{\delta_1}(\delta_1) + N_{\delta_2}(\delta_2) \quad \ldots (11a)$$

$$\overbrace{\left[(K_{\dot{p}} - I_x)s + K_p + \frac{K_\phi}{s}\right]}^{a44} p + \overbrace{(K_r)}^{a43} r + \overbrace{(K_v)}^{a42} v = K_{\delta_1}(\delta_1) + K_{\delta_2}(\delta_2) \quad \ldots (12a)$$

which using the matrix notation defined above gives,

$$\begin{bmatrix} a_{11} & 0 & 0 & 0 \\ 0 & a_{22} & a_{23} & 0 \\ 0 & a_{32} & a_{33} & 0 \\ 0 & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{bmatrix} u \\ v \\ r \\ p \end{bmatrix} = \begin{bmatrix} X_n & 0 & 0 \\ 0 & Y_{\delta_1} & Y_{\delta_2} \\ 0 & N_{\delta_1} & N_{\delta_2} \\ 0 & K_{\delta_1} & K_{\delta_2} \end{bmatrix} \begin{bmatrix} n \\ \delta_1 \\ \delta_2 \end{bmatrix} \quad \ldots (13a)$$

The above matrix equation shows that when considering the linearised equations of motion the ship speed, u, is independent of v, r and p. Speed can therefore be controlled independently of yaw or roll. (It should however not be totally dismissed as the non-linearities which are known to significantly influence the ship speed, in turns say, could be considered in an integrated control system if such a requirement existed. Also the lift characteristics of the hydrofoil control surfaces are dependent on the ships speeds).

The equations of motion can now be reduced to two equations involving the roll angular velocity p and r the yaw angular velocity.

From equation (10a)

$$v = \frac{Y_{\delta_1}(\delta_1) + Y_{\delta_2}(\delta_2) - a_{23}\, r}{a_{22}} \quad \ldots (14a)$$

which when substituted in equation (11a) and rearranging gives,

$$r = \frac{\left[N_{\delta_1}(\delta_1) + N_{\delta_2}(\delta_2)\right] a_{22}}{(a_{33}\, a_{22} - a_{23}\, a_{32})} - \frac{\left[Y_{\delta_1}(\delta_1) + Y_{\delta_2}(\delta_2)\right] a_{32}}{(a_{33}\, a_{22} - a_{23}\, a_{32})} \quad \ldots (15a)$$

Similiarly substituting for v in equation (12a) and rearranging gives,

$$p = \frac{K_{\delta_1}(\delta_1) + K_{\delta_2}(\delta_2)}{(a_{44})} - \frac{\left[Y_{\delta_1}(\delta_1) + Y_{\delta_2}(\delta_2)\right] a_{42}}{(a_{44}\, a_{22})} - \frac{(a_{43}\, a_{22} - a_{42}\, a_{23})}{(a_{44}\, a_{22})} r \quad \ldots (16a)$$

To facilitate diagrammatic representation of equations (15a) and (16a) the coefficient terms are expressed in a more simplified form using the Laplace operator s=d/dt.

$$\text{Coefficient} \quad \frac{1}{(a_{33}\, a_{22} - a_{32}\, a_{23})} = \frac{K_1}{(s^2 + fs + g)}$$

$$\text{in which} \quad K_1 = \frac{1}{(N_{\dot{r}} - I_z)(Y_{\dot{v}} - m)}$$

$$f = \frac{(N_{\dot{r}} - I_z)Y_v + (Y_{\dot{v}} - m)N_r}{(N_{\dot{r}} - I_z)(Y_{\dot{v}} - m)}$$

$$\text{and} \quad g = \frac{N_r Y_v - (Y_r - mU_o)N_v}{(N_{\dot{r}} - I_z)(Y_{\dot{v}} - m)}$$

$$a_{22} = K_2(s + b)$$

$$\text{in which} \quad K_2 = (Y_{\dot{v}} - m)$$

$$b = \frac{Y_v}{(Y_{\dot{v}} - m)}$$

$$a_{32} = N_v = K_4$$

$$\frac{a_{42}}{a_{22}} = \frac{K_3}{(s + b)}$$

$$\text{in which} \quad K_3 = \frac{K_v}{(Y_{\dot{v}} - m)}$$

$$b = \frac{Y_v}{(Y_{\dot{v}} - m)}$$

$$\text{and finally} \quad \frac{(a_{43}\, a_{22} - a_{42}\, a_{23})}{a_{22}} = \frac{K_5(s + a)}{(s + b)}$$

$$\text{in which} \quad K_5 = K_r$$

$$a = \frac{Y_v}{(Y_{\dot{v}} - m)} - \frac{K_v}{K_r} \frac{(Y_r - mU_o)}{(Y_{\dot{v}} - m)}$$

$$b = \frac{Y_v}{(Y_{\dot{v}} - m)}$$

$$\text{also} \quad \frac{1}{a_{44}} = \frac{K_6}{(s^2 + 2\zeta\omega_n s + \omega_n^2)}$$

$$\text{in which} \quad K_6 = (K_{\dot{p}} - I_x)$$

$$\omega_n^2 = \frac{K_\phi}{(K_{\dot{p}} - I_x)}$$

$$2\zeta\omega_n = \frac{K_p}{(K_{\dot{p}} - I_x)}$$

5TH ANGLO-AMERICAN GAS BEARING CONFERENCE

Reported by A. G. Patterson, M.A., M.I.E.E., R.N.S.S.
Admiralty Compass Observatory

Anglo-American Delegates at Admiralty Compass Observatory.

Introduction

The largest yet of this international series of liaison meetings was held at Admiralty Compass Observatory in March. The meeting was jointly sponsored by the U.S. Office of Naval Research and by ACO, acting for MOD(N) as sponsors of the British Gas Bearing Panel. Fifteen members of the ONR Gas Bearing Group came over to join fifty British delegates for two days of papers and discussions.

The chair on the first day was taken by Mr. H. J. Elwertowski, Head of ACO, and on the second day was shared between Mr. S. W. Doroff, Co-Chairman, Administrator of the ONR Group and Mr. A. G. Patterson of ACO, Vice-Chairman. The meeting was opened by Mr. Elwertowski who, in addition to welcoming delegates, gave a short valedictory address in view of his imminent retirement. Mr. Doroff responded, emphasising again the great technical benefits to both nations of this continuing information interchange and paying tribute to all Mr. Elwertowski had done in building up international liaison in this field to its present high level.

FIRST DAY SESSIONS

The first presentation was by **Mr. J. Kerr** (N.E.L. East Kilbride) who described a 120,000 r.p.m. spindle with externally pressurised thrust and self-acting journal bearings which gave very high stiffness with very low air flow.

Mr. W. G. Denhard (Associate Director, Draper Laboratory, M.I.T. Cambridge, Mass.) gave a dissertation on the substantial shortcomings encountered in the gas bearing gyro field between results experienced in practice and those theoretically computed; by differences of over three in some cases. Although partly accounted for by assumptions and inexactitudes in theory and by inaccuracy of manufacture, there was still an unaccountable leeway which had to be made good in hardware at the expense of higher power consumption.

Mr. W. Shapiro (Director, Lubrication Laboratory Franklin Institute, Philadelphia, Pa.) reviewed general gas bearing work at the Franklin and in particular discussed the merits of spiral groove thrust bearing computations based on the narrow groove theory.

Mr. P. Cook (Cranfield Unit of Precision Engineering, Cranfield College) described three air bearing projects in hand at CUPE: an air bearing rotary table with a 72,000 line grating able to resolve 0·9 arc/sec, an externally pressurised gas bearing surface-grinding machine for making self-acting gas bearing components and a similar machine for cylindrical components.

Mr. E. Hall (Associate Director, Draper Laboratory, M.I.T., Cambridge, Mass.) described work of his department for the U.S. Navy in design and manufacturing supervision of gas bearing gyros used in such applications as **Poseidon.** Among new projects of his department were very successful trials of beryllia as a gyro bearing material, which had trebled the start-stop life of some experimental gyros. Glow discharge had been added to his gyro cleaning.

Mr. J. Nelson (M.I.T. Cambridge, Mass.) gave an account of the use of boron carbide as a bearing material in a small gas bearing gyro accelerometer. This material was almost unique in its property of surface improvement as a result of being rubbed against itself, and no boundary lubricant to assist starting was needed for lightweight rotors.

Mr. O. Decker (Mechanical Technology Inc. Albany N.Y.) described two projects on the application of gas bearings to aircraft gas turbines. The first was a turboshaft engine for the U.S. Army where chrome oxide/nichrome bearings would be used to deal with the static and manoeuvring touch-down loads. The second was a turbojet and ramjet in one engine for the U.S. Air Force. The high temperature, high speed, long life capability of air bearings made them ideal for these engines, and between 1975 and 1985 it was planned to include turbine end, main shaft and ultimately gear boxes in the air bearing programme.

Dr. A. R. Lansdown (Swansea Tribology Centre) gave an account of methods in use by his unit for examining microstructure of bearing surfaces. The microcartography system was introduced to Swansea from U.S.A. and had been further developed for tribology use to provide contoured surface maps derived by computation and plotting from a two-dimensional Talysurf readout. The Auger Technique was a highly sensitive means of examining surfaces as thin as a few monolayers and was based on identifying by frequency secondary electrons emitted from an electron-bombarded surface.

Prof. H. G. Elrod (Columbia University, New York) discussed the effects of surface roughness on gas bearings, which could be significant with laminar flow in narrow clearances. Long wavelength roughness was covered by Reynolds equation, but short wavelength or "Stokes" roughness required several effects to be taken into account. Circulating eddies in lathe striations and in grooved bearings were particular cases to be considered.

Mr. J. McCabe (Franklin Institute, Philadelphia, Pa.) described a selection of thrust bearings being studied at the Franklin for space power use in Brayton cycle turboalternators.

Mr. R. Woolley (University of Southampton) reported upon the latest results obtained with Marsh's two dimension vibration apparatus for determining whirl onset speeds in gas bearings.

Mr. D. Dewar (University of Southampton) gave an account of his work in evolving a design method and performance prediction system for spiral groove bearings using oil or grease as a lubricant.

SECOND DAY SESSIONS

Mr. D. Cooke (Royal Aircraft Establishment, Farnborough) considered a method of improving the load-to-size capability of squeeze film bearings. The basis of the method was provision of axial grooving to provide ambient line boundaries to support area which could, on short bearings, improve lift by a factor of two and a half.

Dr. Ralph Burton (North West University, Evanston, Ill.) reported some work of his own and his colleagues on some interaction effects between two sliding surfaces, taking account of frictional heating, wear, thermal conductivity and changes in pressure distribution which occur.

Mr. W. Shapiro (Franklin Inst. Philadelphia, Pa.) reviewed the gas bearing activity at the Franklin, mentioning particularly the turbomachinery bearings used in space power applications, cryogenic machinery, porous bearings, seals and compliant bearings. He further discussed advantages of using numerical methods to solve gas bearing problems and outlined some new concepts such as compliant pad, leaf foil and foil rotor bearings.

Mr. B. Trainer (B.A.C. Stevenage) discussed the considerations of using externally pressurised bearings in instruments, especially the effects of size on mass flow rate and of turbine torques.

Dr. C. Pan (Mechanical Technology Inc., Albany, N.Y.) gave a comparison of his "Narrow Groove Theory" of spiral groove thrust plates with the findings of earlier researchers such as Wildman, summarising the conditions where his theory showed better validity.

Mr. T. Ellis (Royal Aircraft Establishment, Farnborough) described the methods developed by RAE and Ferranti, Edinburgh, for making spiral grooved cones for the modified Kearfott 2519 gyro.

Mr. J. Publicover (M.I.T. Cambridge, Mass.) gave an analytical account of start failure mechanisms in ceramic gyro bearings due to debris. Finely divided alumina, excess lithium stearate (used as a boundary lubricant) and products of epoxy resins had all been detected by the sensitive analytical techniques employed. Prominent among these were mass spectrometry, scanning electron, microscopy, electron microprobe and x-ray diffraction. In addition to obvious corrective actions, M.I.T. were now using domestic pressure cookers to decontaminate gyro bearing components.

Dr. I. S. Donaldson (Queens University, Belfast) gave a progress report on his work with porous inserts for externally pressurised bearings and described his loading pad, porous bearing test rig and some results obtained with it.

Mr. Glen Rightmire (Columbia University, New York) described his work at Columbia in using tilting pad bearings with compliant surfaces, giving results of pressure distribution obtained by use of crystal transducers.

Prof. V. Castelli (Columbia Univ., New York) discussed the effects of inertia and viscoelasticity in bearings with a compliant surface such as rubber, dealing both with slider and journal configurations.

Mr. P. Szego (Ampex, Redwood City, Cal.) summarised gas bearing work in progress at Ampex and described in detail air bearing applications to rotating mirror scanning systems for laser beam recorders and high speed photography.

Mr. A. Huxley (A.C.O.) in giving a progress report on A.C.O. work on squeeze film bearings made a comparison of the observed experimental behaviour of a number of conical and hemispherical bearing assemblies in sandwich configuration, similar crystals being used throughout. In addition, he described the driving circuits used and explained his systems of instrumentation.

At the conclusion of the first day's proceedings a cocktail party was held for delegates and friends at A.C.O.

At the conclusion of the formal meetings, the appreciation of American delegates was voiced by Prof. H. Elrod (Columbia University) who expressed his group's hopes for long continuation of this international liaison. Delegates then made a general tour of a number of A.C.O. laboratories before visiting A.C.O.'s own gas bearing facility to discuss work in progress.

During the remainder of the week a series of visits was arranged in which various members of the British Gas Bearing Panel became hosts at their respective establishments to members of the American Group sharing similar interests.

CORRESPONDENCE :

To The Editor,

Journal of the Royal Naval Scientific Service

MISCELLANEOUS MEMORIES

These memories are definitely not scientific but may be of interest bearing in mind " that there is nothing new under the sun ".

On joining, my first ship, H.M.S. *Marlborough* " at Sheerness, on a Friday in July 1930, I was detailed the following morning at Quarters Clean Guns to clean the Sub Calibre of P5 6 in. gun. The sub calibre was a miniature edition of the 6 in. gun which fitted inside of the bore and in the interests of economy was used for practice firing using a much smaller projectile and a much smaller charge of propellant. It was a beautifully highly burnished piece of mechanism, but being unable to find metal polish or cotton waste, and too scared to ask, I used a bit of emery cloth. The Battery Gunner's Mate nearly jumped over the side when he found what I had done and it took ages to live down my grave error. In fact, my mess-mates made a little song about it to the tune 'Michael Finnigan.' The words were " There was a boy named Jock McLanachan, he put emery on the sub-calibre ".

In these ships boys were messed in the casements alongside the 6 in. guns and of course during shoots all mess tables, stools etc., had to be cleared away. It was similar to Nelson's days when gun crews messed alongside their guns. The mess tables were covered by oil cloth, and, as boys were careless the oil cloth became rather " tatty " after a few weeks in use. Per the Rules and Regulations, messes were entitled to a new tablecloth every six months but in the interests of economy this was seldom done.

However, when an Admiral's inspection was forthcoming we were promptly issued with a new tablecloth. A few days later, during the General Knowledge part of a Seamanship Exam, one of the boys was asked how often his mess was entitled to a new tablecloth. When he replied " every time there is an Admiral's inspection," he was soundly cuffed by the examiner for being facetious.

In the same ship, a boy was being questioned on ship construction by the boatswain in his cabin. The boatswain said " Now, son, tell me what a rigol is ". (A rigol, in fact, is a semicircle above a porthole to prevent water running down the ship's side and seeping through the port). The boy sadly shook his head and said " Sorry sir, I don't know ". " Well ", said the boatswain, trying to be helpful, " stick your head through that porthole and have a look ". " No thank you ", said the boy, " I'd sooner pass on my merits ".

From my submarine days I also recall an amusing incident, though it also had a note of tragedy attached to it. I was Torpedo Instructor of a submarine and we had just returned alongside the depot ship H.M.S. *Forth* in the Holy Loch after a very strenuous three weeks patrol off Iceland. Unfortunately by the time I got onboard to have a bath, nine pm rounds were in progress and I was refused permission to use the PO's bathroom.

On my way back to the submarine I was stopped by a messenger from the submarine Regulating Office who said " Excuse me PO, are you untamed ? " I said " I don't know about untamed but I'm ——— fed up with this ——— Depot Ship. Actually, what had happened was that the submarine *Untamed* had failed to return from exercises in the Clyde and the office was checking for crew who hadn't sailed in her. The *Untamed* was later found (there were no survivors) and salvaged by the Diving Vessel *Tadworth*. She was re-commissioned and re-named *Virulent*. The cause of her loss was a common fault of submarines at that time and was a combination of human and mechanical error. The sluice valve which opened and shut to allow exit of the chernikeef log sometimes showed " shut " when it wasn't fully home. If one attempted to open up the top of the log with the sluice valve not fully shut, water under pressure quickly flooded the compartment.

W. Y. McLanachan
Commander, R.N. (Retd.)

OBITUARY

William Edward Leslie Taylor

His many friends were shocked to hear of the sudden death of Leslie Taylor at his home on the Spring Bank Holiday, May 29th, 1972. Although approaching 60, his enthusiasm for his work was unabated and Superintendent Admiralty Oil Laboratory had hoped to retain his services as the P.S.O. in charge of AOL's Material Characterisation Group after his 60th birthday in February 1973.

Leslie Taylor studied at Hull Technical College, his home town, and obtained an external B.Sc. in chemistry from London University. He joined the Admiralty Chemical Department in Portsmouth Dockyard as an Assistant III on March 18th, 1937 where he was employed on the analyses of a variety of materials, until he was transferred to the Admiralty Fuel Experimental Station on May 1st, 1944.

At AFES he was involved in many aspects of furnace fuel oil quality and also its handling and use within the Navy. Work in support of the establishments boiler programme included sea trials and by his readiness to tackle problems when and where they ocurred, as well as at the laboratory bench, he built up a thorough knowledge of fuel storage and handling systems ashore and afloat. On January 1st, 1952 he became an SXO and for a time before he transferred to AOL on April 1st, 1956, he was the senior civilian at AFES. He became a CXO on March 1st, 1960, in charge of the Material Characterisation Section at AOL.

The first major problem in which he was involved was establishing a means of treating substantial quantities of emulsified furnace fuel oil and recovering the fuel. Emulsions can be formed especially when fuel tanks have to be ballasted with sea water or when water is used to displace fuel from tanks to maintain a ship's trim. Emulsions of high sea water content are viscous and do not readily burn. At lower water contents they burn but cause severe slagging and corrosion in ships boilers.

Another major problem was the tendency of some furnace fuel oils to become unpumpable or nearly so in storage at UK winter temperatures. This became a full scale investigation in conjunction with the oil industry through the Navy Department Fuel and Lubricants Advisory Committee, with full scale pumping trials in depots and on board ships and extensive work in the laboratory until it was solved. Taylor was a key member of the AOL team involved.

Always very interested in the subject of oil pollution on beaches, Taylor was seconded for some weeks to help an MOD team tackle the polluted Cornish beaches when the *Torrey Canyon* ran aground. Afterwards he took part in a survey of the effectiveness of the methods used round Cornwall and in Brittany. The emulsions of crude oil and sea water which form after oil is spilt on the sea are similar in many respects to the fuel oil emulsions he had tackled.

He took a key part in fitting out AOL's present premises at Cobham, where he had continued to take a personal interest in DFMT's problems especially those relating to obtaining fuel in bulk from world-wide sources.

A keen supporter of AOL Sports and Social Clubs he served as treasurer and commitee member for several years. When he first joined the Civil Service he played football, cricket and tennis with Portsmouth Civil Service and as a club official took his share of the work of organising matches. At AOL he was an enthusiastic member of AOL's bridge team and was recently seen practising golf. His abilities in do-it-yourself home improvements were considerable. This talent also showed in his ability to keep trials equipment working afloat or ashore and get results under adverse conditions.

Our deepest sympathy goes out to Mrs. Taylor. We are glad that she has the strong support of her son and son-in-law.

NOTES AND NEWS

Admiralty Surface Weapons Establishment

In July the Establishment welcomed two overseas visitors—Dr. R. H. Richard and Mr. M. E. Burgess—who have come to spend a year working in ASWE.

Dr. Richard studied at the John Hopkins University, Baltimore, U.S.A., and obtained a Dr. Eng. degree from there in 1962. He is currently a member of the Professional Staff of the Systems Evaluation Group at the Centre for Naval Analysis, Arlington, Virginia and is visiting ASWE under a one year fellowship granted by CNA.

Mr. Burgess graduated from Imperial College in 1966 and stayed on in Australia after visiting the country. He works at the RAN Research Laboratory, Sydney, NSW as a Research Scientist in the Operations Research Group.

Both are now members of the Assessment Division at ASWE. Their friends and colleagues at ASWE wish them and their families a happy stay in England.

On 20th July 1972 Mr. S. T. Wright, Mr. E. J. W. Underhill, Mr. R. L. Short and Mr. B. R. Gladman visited Ulm, near Munich, West Germany, at the invitation of AEG-Telefunken to discuss work on a phased array aerial system used in a coastal-zone surveillance radar, a pulse-doppler fire-control radar MARDER and a proposed small ship radar and data system KAGOS. In addition to the paper and film presentations they visited a trial site to see the MARDER system working in conjunction with simulated targets.

Dr. H. A. French, Mr. E. Denison and Mr. R. G. Taylor recently attended an intensive short course on "Radar Signal Processing and Clutter" at Stockholm in Sweden. The course, which covered all the recent theoretical developments in the field was presented by Technology Service Corporation of Santa Monica, California, and was attended by some 50 scientists from 11 countries.

Mr. N. E. Gubbey, PSO, rejoined the establishment on 9th September after spending two years with the Plessey Company as a Fulton exchange scientist, and has been posted to the Assessments Division.

Obituary

It is with deep regret that we announce the death of **Mr. Stanley (Mick) Stroud,** PTO II, who died after an illness lasting three months at St. James' Hospital on Monday, 26th June at the age of 54.

Born in Portsmouth, Mick entered Portsmouth Dockyard from St. Luke's School in 1934 where he served in the MED until promoted to the position of draughtsman in the Torpedo Tube Design Office in 1940 where he served for nine years, the majority at West Howe after the office in the yard was bombed out.

In 1949 he was transferred to the Admiralty Mining Establishment Drawing Office where he served for 10 years at Havant and Portland until 1959 when he was transferred to ASWE. In 1962 after serving continuously as a draughtsman for 22 years Mick was promoted to Leading Draughtsman and had since 1962 been employed in the Installation Division.

Mick was a keen member of the ASWE and Eastney Sailing Clubs and also enjoyed the solitude of fishing from a dinghy which he built himself.

Mick's funeral took place at Portchester Crematorium on 30th June and was attended by many of his friends and colleagues from ASWE. His presence will be sadly missed and our sympathy is extended to his mother on this very sad occasion.

With the retirement of **Mr. A. L. P. (Monty) Milwright,** the now small band of scientists who served the Navy throughout the whole of the last war, is significantly reduced.

Monty joined H.M. Signal School as a TEA III in 1938 from E. K. Cole Ltd. after a spell of nine years in the radio industry spent with three different firms. He worked initially on VHF transmitters but after little more than a year was moved to Bristol University (H. O. Wills Physics Laboratories, in Admiralty occupation) to join the team led by R. W. Sutton working on velocity modulated oscillators (the 10 cms. wavelength, high voltage Sutton tube). These tubes were a vital part of all the early microwave radars.

By 1941 he was back again in Signal School at Eastney (now as a TEA II) where he joined the receiver division (H. E. Hogben regnant) to work on transponders for the secondary radar systems then known only as IFF (Identification Friend or Foe). These systems were in a vital and urgent state of development and the work involved hazardous trials with aircraft, both from ground stations and carriers. Monty's great flair for mixing himself with action, and his easy gift of converse with all types of serving officers and personnel really came into its own in this work. He met every challenge, the worries he had rarely showed, and he could, where necessary, be imperturbable to the verge of urbanity. He was promoted to TEA I in 1943, and towards the end of the war he served for a year in Washington on a mission concerned with integrating the Mark X IFF system (then the L-Band heir presumptive to the VHF Mark V) into the British Services.

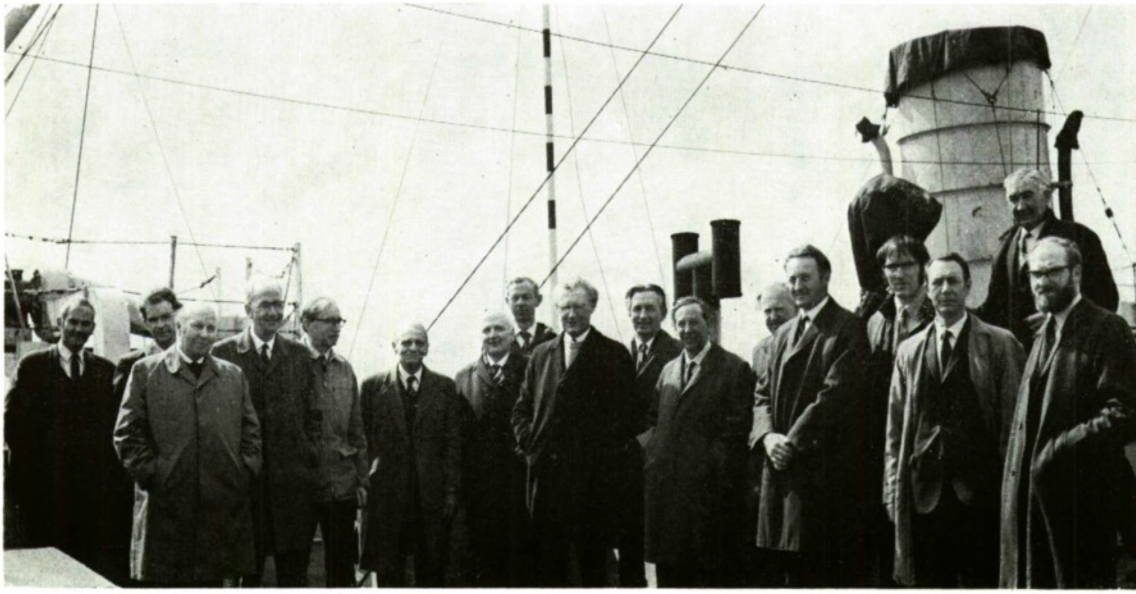
In 1946 he was involved, still under H. E. Hogben, with the development of a prototype X-band radar set aimed at fulfilling the requirements of a navigation aid for Merchant Ships. This prototype was fitted in H.M.S. *Fleetwood* and a period of demonstrations in European waters (to all the shipping interests) ensued, with Monty as one of the experts in attendance. He was promoted to SEO in 1947 and when the Civil Marine Division (TX) of A.S.R.E. (now A.S.W.E.) was set up under H. E. Hogben, Monty headed the Section dealing with the type testing (to Ministry of Transport Specification), of the flood of Civil Marine Radars then being developed by British Industry. During this period (1957) he became personally engaged by the problems of the radar detection of small icebergs (growlers), and designed an experimental investigation which occupied him for some two months on a voyage into arctic waters in a Canadian Icebreaker. The papers he wrote on this are still a standard reference when numerical data is required. In 1953 he was promoted to P.S.O. and became Head of the Civil Marine Division, a post which he held for 10 years, becoming widely known and greatly respected in the Navigational Aids Industry.

In 1964 Monty moved to the Communications Department of A.S.W.E. becoming Head of the Ground Stations Division at a difficult time of contraction in our overseas bases. He has essentially a sharp numerate mind, and quite rapidly acquired a fundamental operational knowledge of the various communications systems involved. He was soon, for instance, discussing the pros and cons of the then new HF log periodic antennas, compared with Rhombics as space savers.

A final appointment (1969 onwards) entirely in his line, was as scientific adviser to the Far East Fleet at Singapore. It was here, unfortunately, that his charming and vivacious wife Kay died after a tragically sudden and brief illness.

Throughout his long career in the R.N.S.S. Monty was never more happy than in his dealings with uniformed officers of all services. At Eastney he was for years a member of the Royal Marines Officers' Mess, joining in many of their activities, both in work and play, and he had, on leaving the Barracks the rare privelege of being made both an Honorary Member of the Mess and presented with a Royal Marines tie.

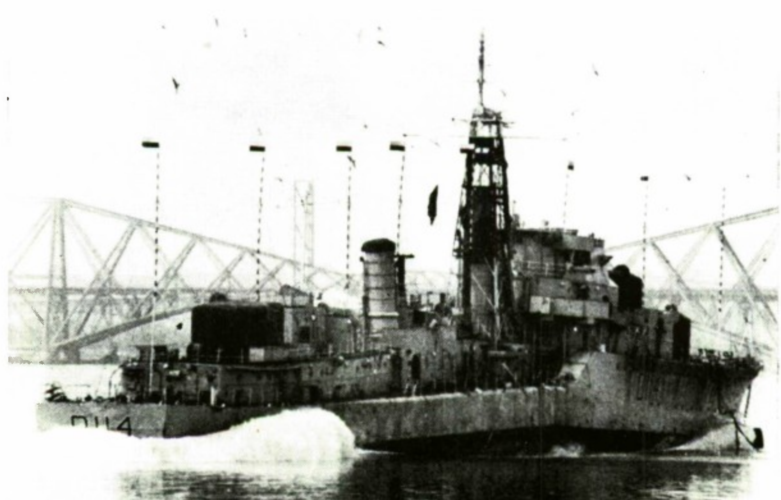
Monty is retiring to a spacious bungalow near Brecon, with a vista of the Welsh mountains. But with his three children successfully settled in various parts, one with Australian Airlines, he intends to travel widely to see the many friends he has made all over the world. At a farewell ceremony at Portsdown, on August 30th, he was presented with a claret decanter, and a silver punch bowl of ample proportions, as parting gifts from his colleagues. We all wish him a long and active retirement.



Hull Committee on board H.M.S. *Defender*.

The Hull Committee of the Maritime Warfare Advisory Board of the Defence Scientific Advisory Council—Chairman Professor E. W. Parkes, Cambridge—visited NCRE on 1 and 2 May 1972. The object of the visit was twofold, to discuss the NCRE Applied Research Programme on Glass Reinforced Plastics and to observe the final underwater explosion test on the series of Whipping Shots against the destroyer H.M.S. *Defender*.

Recently NCRE assisted the Institute of Geological Science to carry out a further series of Seismic shots by providing the services of their instrument vessel R.M.A.S. *Barfoot* and their Explosives Officer, Mr. C. C. Moore, O.B.E. A series of 300 lb charges were fired off the North of Scotland and in the Minch and a single 10 ton charge was fired off the Island of Rhum on 11 June 1972. The reverberations of this explosion were picked-up by seismic stations all over the world.



Whipping trial on H.M.S. *Defender*.

BOOK REVIEWS

Underwater Science. Edited by J. D. Woods and J. N. Lythgoe. Pp. 330 + xiii; Oxford University Press, 1971. Price £4.

In this book nine experienced British divers describe contemporary trends in underwater science with emphasis on the practical aspects of underwater experimentation. The majority, if not all the authors, are members of the Underwater Association which has provided many an undergraduate with his or her first application of scientific principles to research in the underwater environment. Subsequently this interest has followed them into their working lives as with the case of many of the authors of this book.

Although underwater photography is rightly or wrongly not considered in great detail, due, it is stated, to the large amount of literature already available, a brief account is given of contemporary photographic equipment and some applications of photography to scientific work. Since the editors do, however, point quite rightly to the importance of this specialist photography, it might well have added to the value of the book to have included a more detailed account of this vital skill and, perhaps of even more importance, also the physiological and medical hazards of diving which are rather lost in the enthusiasm of the authors for their work. A simple account of these would have provided necessary balance.

However this does not detract from the value of this well produced book as an introduction to the variety of scientific research that can be performed by both the specialist and the amateur scientist who is absorbed with the marine environment. Thus after a brief Preface the editors discuss "Apparatus and Methods for the Diving Scientist" followed by a further eight chapters: "Diver Performance", by A. D. Baddeley; Spatial Perception Underwater, by Helen E. Ross; Vision, by J. N. Lythgoe; Fish Behaviour, by C. M. Hemmings; Botany, by E. A. Drew; Archaeology, by Joan du Platt; Geomorphology, by N. C. Flemming and Micro-oceanography, by J. D. Woods.

There are 104 figures consisting in the main of very good line drawings, a few black and white photographs and one colour plate. The editors are to be congratulated on the excellent uniformity of style in the illustrations, as indeed is found also with the text. One of the most difficult problems of editors of a multi-author work of such diversity is to maintain a uniformity of style to prevent the book being just a bound version of a number of separate papers. The editors have avoided this pit-fall very successfully with this book.

Each chapter includes a more than adequate list of references to lead the reader beyond the easily read style of this book to the perhaps more erudite but less readily absorbed, scientific papers and books. There is also a fine Author Index and less satisfactory General Index which could have been rather more informative than the long lists of flora and fauna which are found.

All units are given in metric which is in keeping with contemporary practice in this country. However in the interests of North American purchasers and to those British readers still becoming familiar with such units, it might have been valuable to have given the equivalent depth in feet after that given in metres, or at the least a simple conversion table at the start of the book.

The initial chapter by the editors is a pot-pourri of topics such as the inefficiency of man underwater, training and safety, breathing apparatus, heat loss. underwater houses, transportation, communication, and recording methods. It is perhaps unfortunate that so much space and a full page drawing is given of the Starck-Kanwisher electrolung. The comment that " the average dive of 90 m uses less than $\frac{1}{3}$ of the helium supply and the oxygen is sufficient for four to six hours " without discussing the very severe decompression problems of such long, deep diving is courting a considerable increase in the already high incidence of decompression sickness in over enthusiastic amateur divers.

The second chapter on Diver Performance is limited to nitrogen narcosis and visual performance in relation to the divers visual field and acuity. The narcosis data is most useful for the work by its author on narcosis underwater rather than the more common method of simulated dives in pressure chambers and for discussion of the many pit-falls in planning and executing such experiments.

The chapter by Dr. Ross also considers vision but concentrates on visual judgment of size, distance and orientation which emphasises the perceptual difficulties of working in this strange environment. Vision is concluded in the next chapter by J. N. Lythgoe who mainly considers the problem of changing colours underwater. Each of these chapters is complementary to the other and the editors are to be congratulated on reducing repetition to a minimum.

Chapter five by Dr. Hemmings reflects his long practical experience of " fish watching " in their own environment and is a fascinating account of the problems and what can be learned of fish behaviour by the marine scientist/diver, as is the following chapter on Laminaria and algae and the chapter on Archaelogy by J. du Plat Taylor. The latter, in particular, emphasises the dangers of looting and destruction of many precious finds and the need for specialist archaelogical supervision in this work.

The final two chapters are concerned with the ocean itself and the geomorphology of the continental shelf, the chapter by Dr. Fleming laying emphasis on the part the diver may take in such work and the techniques to be used by the underwater geologist. The concluding chapter by J. D. Woods discusses the thermocline and his extensive and excellent scientific work with dye tracers leading to the unexpected discovery that a large proportion of the thermocline exhibits laminar flow. This chapter shows in elegant fashion the fine results which can be achieved, often with the most simple of equipment, by the marine scientist who is anxious to explore this very different environment which is becoming of rapidly increasing importance.

The book will no doubt be on the book shelves of all sub-aqua clubs and can also be read with benefit by all scientists who contemplate using their skills in the marine environment.

P. Bennett

NOTICE TO READERS

The Editor extends to all readers of the Journal and particularly those of the younger generation, a cordial invitation to contribute articles of R.N.S.S., naval or general scientific and technical interest.

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Views and opinions expressed in the Journal are not necessarily endorsed either by the R.N.S.S. or by the Editor.

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